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Final Report

PSYCHOLOGICAL EXPERIMENTS ON SONIC BOOMS CONDUCTED AT EDWARDS AIR FORCE BASE

Prepared for:

NATIONAL SONIC BOOM EVALUATION OFFICE
1400 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22209

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Final Report *August 1968*

PSYCHOLOGICAL EXPERIMENTS ON SONIC BOOMS CONDUCTED AT EDWARDS AIR FORCE BASE

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ABSTRACT

A total of approximately 300 subjects, 100 of whom had been exposed for an average of two and one-half years to about seven sonic booms per day, were located outdoors and in houses at Edwards AF Base specially constructed to be representative of typical midwestern USA houses for the 1970's. The subjects were exposed to pairs (one sound followed shortly by a second sound) of sonic booms, pairs of a sonic boom and the noise from a subsonic aircraft, and pairs of noise from subsonic aircraft. The subjects judged the relative acceptability of the sounds in each pair and also rated each sound on a numerical scale from very acceptable to unacceptable. The results showed that subjects exposed to booms for several years were considerably more tolerant of booms than persons without this previous exposure, but even so the previously exposed persons judged the boom from either a F-104, B-58, or XB-70 of about 1.7 psf to be no more acceptable than the noise from a subsonic jet aircraft at a peak level of about 109 PNdB. In the booms tested, the energy, from about 20 to 500 Hz is primarily responsible for the reaction of people to the booms.

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I INTRODUCTION

Most of the energy in the typical sonic boom as measured outdoors is in the low-frequency region, giving the boom an audible "thud" characteristic; in addition, there are briefly present significant amounts of energy at the higher frequencies due to the abruptness with which the wavefront goes from ambient to peak positive pressure and returns to ambient pressure from peak negative pressure. These portions of the boom where the pressure is rapidly changing in intensity gives the boom a sharp audible "crack." For a given change in pressure, the more quickly (rise time) this pressure change takes place, the greater the subjective sharpness of the "crack." If there is sufficient temporal separation between the beginning and end portions (the duration) of the sonic boom and if each of the two portions is of a sufficient intensity, the listener will hear two cracks rather than the one crack due to the initial portion of the wavefront.

The way in which the human auditory system perceives impulse sounds such as the sonic boom has been and is being studied under laboratory conditions at the University of Southampton in Great Britain and at the Lockheed-California Company in the U.S.A. It has been found in these studies[26] that subjective intensity (loudness or perceived noisiness) of a simulated outdoor sonic boom pressure signature is to a first approximation determined by the frequency spectrum of the energy in the booms and can therefore be calculated or predicted from knowledge of this spectrum.

Although the effects of the sonic boom upon people outdoors are of considerable interest, the fact remains that people indoors object as much if not more to the effects of environmental noise, even though the noise itself is generated outdoors and even though the house or building structure attenuates and reduces somewhat the intensity of the sound. This is usually attributed to the fact that people indoors demand and have a greater need for protection against noise because their indoor

activities differ from their outdoor activities and perhaps because they spend more time indoors.

In the case of the sonic boom it is possible that the sonic boom and the house will interact in such a way that the interference effects on humans are augmented more than are other externally generated sounds, the reason being that components of the house structure are driven beyond their usual response and make the house "rattle," "creak," etc. In any event, it seems likely that the effects of sonic booms on people indoors will strongly determine acceptability to people to the sonic booms.

Research has been conducted previously on this question and other related questions regarding the subjective response of people to noise using the so-called paired-comparison psychological tests in which listeners are asked to express their preference for one of two sounds presented within a brief period of time.[1,3,6,7,8,10,14,16-18,20-25] By means of the paired-comparison tests, one should be able to determine the relative effectiveness upon human response of sonic booms that differ with respect to their duration, rise time, or other signature variations. Such information could serve as design criteria for the development of supersonic aircraft that generate sonic booms that are the most acceptable to people located under or near their flight tracks.

Of more practical importance than knowing the relative acceptability to people of different types of sonic booms is the question of how acceptable these sonic booms will be to people when the booms are judged in terms of their acceptability under everyday living conditions and as a part of commercial aviation. Paired-comparison tests can also serve as a means of indirectly determining how people might accept and what they might do about sonic booms of various sorts when heard in their homes and when the booms were generated by commercial supersonic aircraft. This can be done by having one of the sounds in the pair be a sonic boom and the other be a sound from commercial aircraft for which we know the negative and positive values people hold in terms of political, legal, and social behavior.

It is, of course, to be understood that the paired-comparison tests, particularly involving two sounds that differ, require some validation before they can be accepted with confidence. Fortunately, in the present case this has been done to some extent for the sonic boom (studies at Oklahoma City[4] and France[11]), and particularly for the noise from commercial aircraft near busy metropolitan airports.[9,12,16]

The precision with which the relations between the physical and psychological effects of sonic booms and between sonic booms and the noise from subsonic aircraft can be determined is limited by the availability and characteristics of supersonic aircraft for generating the required sonic booms or of equipment whereby different types of sonic booms under laboratory conditions could be simulated. At the time the psychological experiments to be reported were planned, simulators that could generate sonic booms with complete fidelity were not available, although, as aforementioned, some tests have been conducted in the laboratory with simulations of both indoor and outdoor sonic booms.

With this background of information, the following series of experiments using military supersonic and subsonic jet aircraft were planned for prosecution at Edwards Air Force Base:

1. Paired-comparison tests and absolute ratings of the relative acceptability of sonic booms with the flyover noise from subsonic jet aircraft, the subjects being placed both indoors and outdoors during the tests

2. Paired-comparison tests and absolute ratings of the relative acceptability of sonic booms from one type of supersonic aircraft to sonic booms from a second type, and of sonic booms from the same type of aircraft but flown under different operational conditions

3. An attitude survey of the acceptability of the sonic booms to residents in a military community habitually exposed to sonic booms.

II PROCEDURES FOR PSYCHOLOGICAL TESTS

Subjects selected from residents of the communities of Edwards Air Force Base, Fontana, and Redlands, California, were assigned to the various indoor* and outdoor test sites at Edwards Air Force Base (see Table 1). The instruction sheets and answer sheets were discussed with the subjects by the test monitors. One monitor was provided for about 20 subjects in each test room or area.

The aircraft sounds were presented in pairs with approximately one to two minutes between the members of each pair and a minimum of approximately four to five minutes between pairs. Each experimental test condition was repeated four times, twice with sound A of the pair given first in the sequence, and twice with sound B of the pair given first. The schedule of test missions and conditions for all the paired-comparison tests is given in Appendix A.

The subjects' main task was to indicate on an answer sheet which sound of each pair was the more acceptable if heard in or near their homes. They also were required to rate on a 13-point scale the acceptability of each of the sonic booms or sounds heard on certain days. A set of the instructions to the subjects and the answer sheet are in Appendix B.

Approximately one minute before the first sound of each pair, the subjects were advised that a sound would soon occur. The subjects were allowed to chat among themselves, knit, read, etc., but were admonished not to discuss their answers nor were they permitted to engage in loud conversation during the presentation of a pair of sounds. The subjects

---

*The test houses at Edwards designated as "E-1," and "E-2" were centrally air-conditioned and, except for one of the rooms, the door of which was kept closed, the windows and exterior doors of the house were closed during all the tests. The masonry "block house" used for some of the tests was not air-conditioned, but the windows and doors were kept closed.

Table 1

BIOGRAPHICAL DATA FOR THREE GROUPS:
EDWARDS, FONTANA, REDLANDS

	Edwards	Fontana	Redlands
Sex and Marital Status			
Single Male	1%	4%	12%
Married Male	12%	21%	28%
Total Male	13%	25%	40%
Single Female	3%	4%	7%
Married Female	84%	71%	53%
Total Female	87%	75%	60%
Male Occupations			
Air Force	79%	4%	0%
Retired	16%	25%	46%
Other	5%	71%	54%
Female Occupations			
Housewife	94%	92%	75%
Retired	1%	0%	11%
Other	5%	8%	14%
Average Age (years)			
Male	36.9	44.0	50.8
Female	33.7	38.7	49.2
Total	34.2	40.0	49.8
Education (Ave. yrs. Completed)			
Male	12.3	13.1	13.2
Female	11.8	11.9	13.1
Total	11.8	12.2	13.1
Total Biography Cards	142	98	153

were paid $1.50 per hour and appeared to be highly motivated and interested in the tests. The test results indicate that the subjects were attentive and reliable.

In addition to the test subjects, data were obtained from 50 percent of the residences at Edwards Air Force Base regarding their ratings or attitudes on a scale of the "acceptability" of sonic booms, the noise from subsonic aircraft, and street noise at and in their homes. This information was obtained by means of a mail survey conducted after the sonic boom test program was completed. The instructions and questionnaire used for the attitude survey are in Appendix C.

III RESULTS

A. Boom vs. Subsonic Noise

Figure 1 shows a plot of typical results obtained from the judgment tests. The intensity level at which 50 percent of the subjects rated one of the sounds in Fig. 1 (the noise from the KC-135 subsonic jet aircraft) equal in acceptability to the other sound in Fig. 1 (the sonic boom from the B-58 at a nominal peak overpressure of 1.69 psf) was taken as the point at which the sounds are equally acceptable to the subjects. Table 2 gives the intensity, in peak PNdB*, required for the noise from the subsonic jet aircraft to be judged equal in acceptability to the sonic booms; these data in Table 2 are taken from the graphs in Figs. 1, 2, 3, 4, and 5. Peak PNdB, although commonly used, is but one method for expressing the intensity of a noise. It is perhaps of interest to show the levels in other units used for this purpose of the aircraft noise when judged equal to the sonic boom. This is done in Table 3 for sonic booms from the F-104. The question of which of these units best measures the subjective noisiness of aircraft noise insofar as the present tests permit an answer to this question, will be discussed in Section D below.

The inclusion of additional physical measurements of the noise from the subsonic aircraft not yet analyzed when the "Interim Report" of the Sonic Boom Experiments at Edwards AF Base was published in July 1967

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*Full definition and procedures for the calculation of units of perceived noise level, such as peak PNdB and others specified in Table 2 and 3, are to be found in ref. 20. In brief, "peak PNdB" is calculated from the highest level reached during a flyover noise in each 1/3 or full octave band. The Max PNdB is the largest PNdB calculated from band measures taken every 0.5 s during a flyover noise; $PNdB_t$ contains a pure-tone "correction" factor; E_dPNdB is the integrated value of PNdBs measured in successive 0.5 s-intervals of time during a flyover noise; and $E_{0.5}$PNdB and E_{15}PNdB are integrated values related to a reference duration time (i.e., 0.5 s or 15 s respectively). These and related units of measurement will be discussed more fully in Section D below.

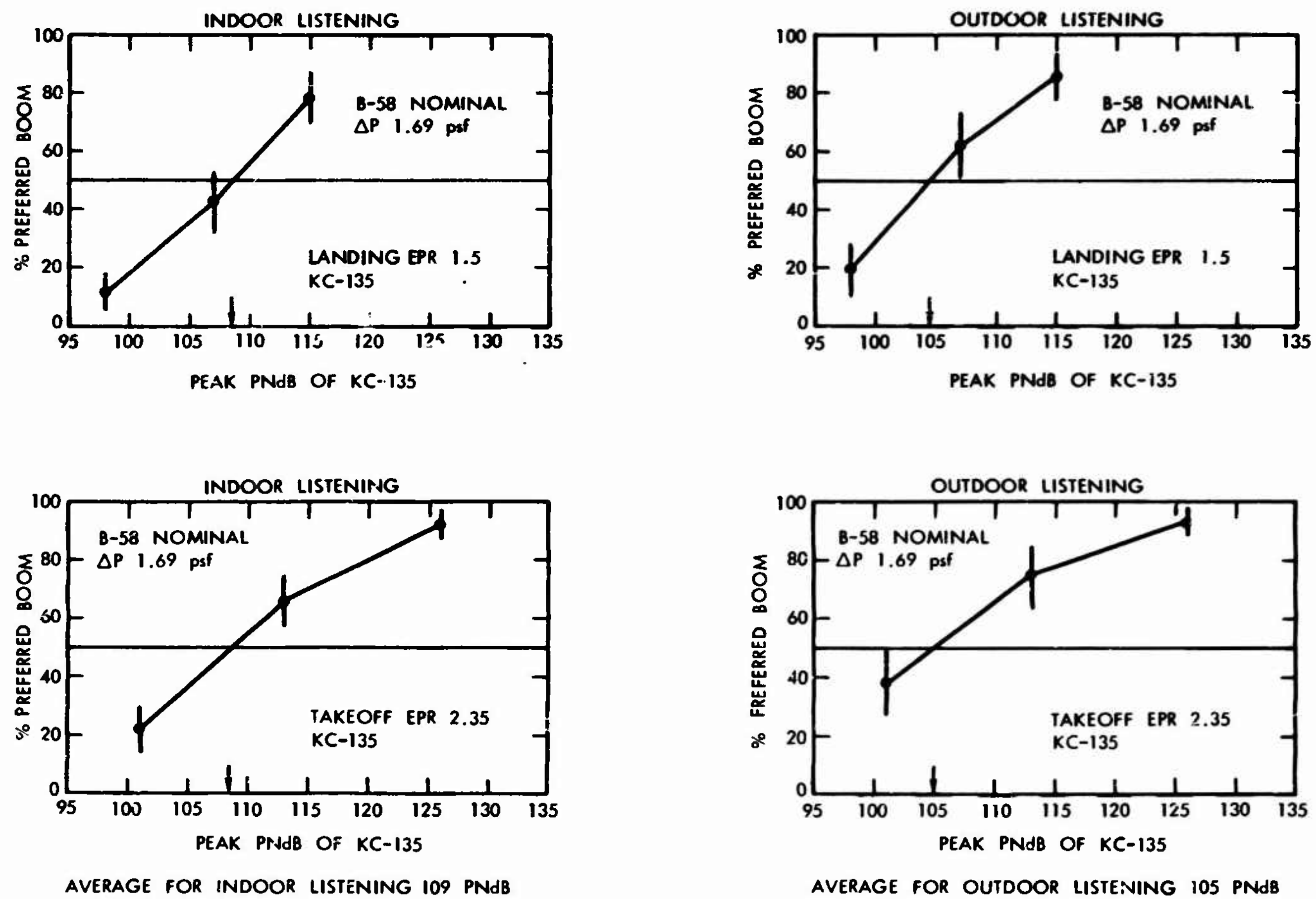
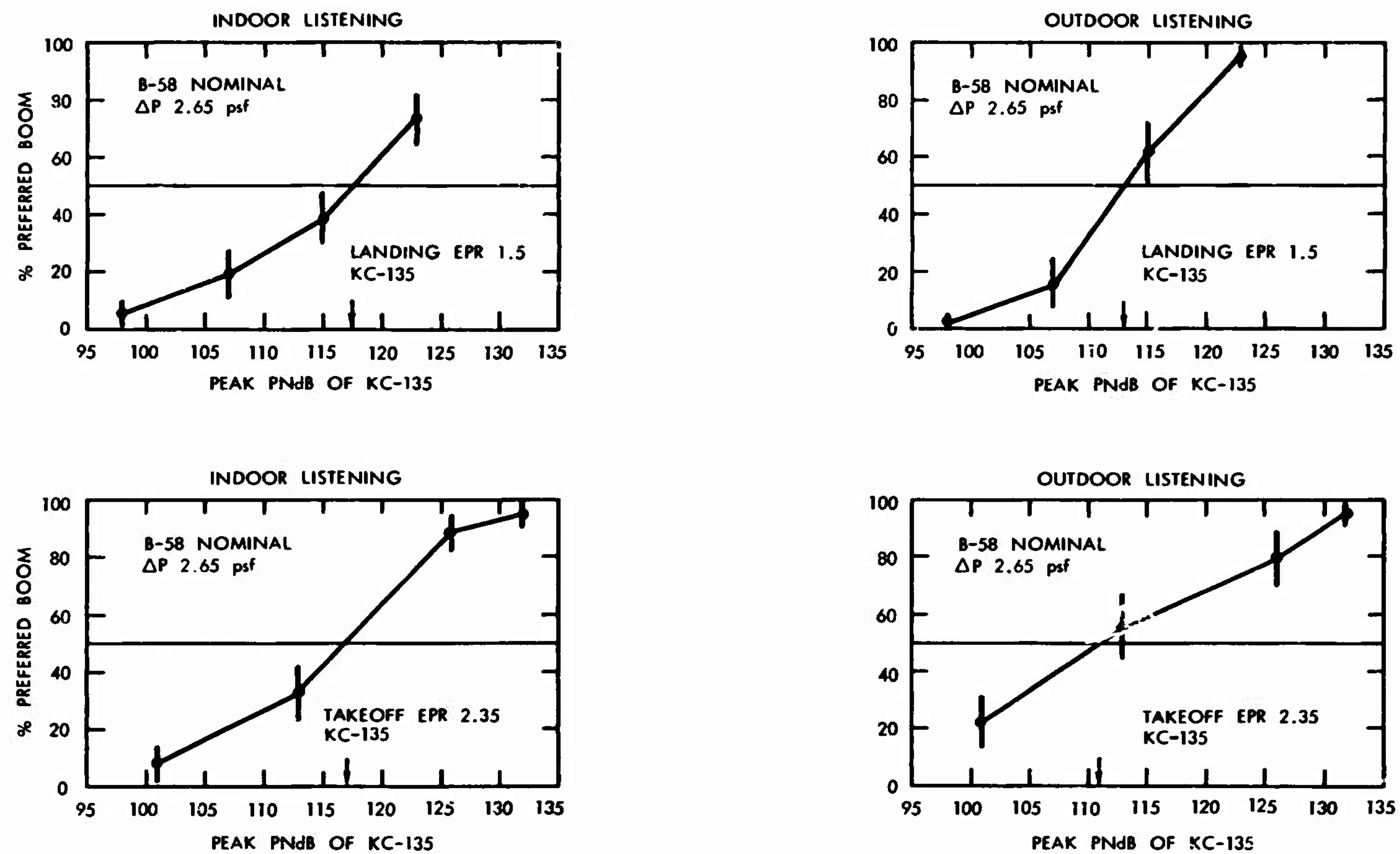


FIG. 1 RESULTS OF PAIRED-COMPARISON JUDGMENTS OF SONIC BOOM vs. SUBSONIC NOISE (B–58 nominal ΔP 1.69 psf vs. KC–135). The vertical bars mark the 90% confidence limits of plotted data points. Listeners from Edwards AF Base – Phase I.



AVERAGE FOR INDOOR LISTENING 117 PNdB

AVERAGE FOR OUTDOOR LISTENING 112 PNdB

FIG. 2 RESULTS OF PAIRED-COMPARISON JUDGMENTS OF SONIC BOOM vs. SUBSONIC NOISE (B-58 nominal ΔP 2.65 psf vs. KC-135). The vertical bars mark the 90% confidence limits of plotted data points. Listeners from Edwards AF Base – Phase I.

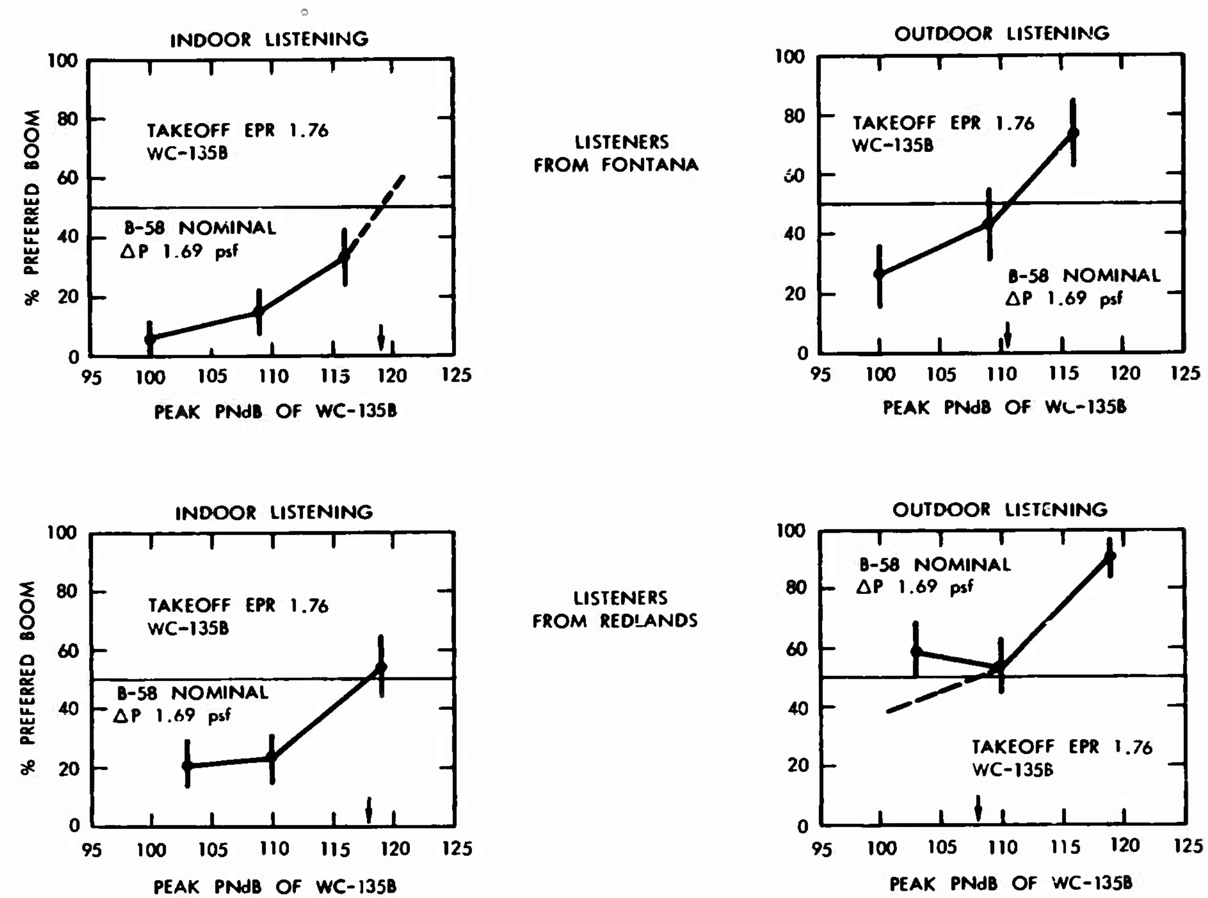


FIG. 3 RESULTS OF PAIRED-COMPARISON JUDGMENTS OF SONIC BOOM vs. SUBSONIC NOISE (B-58 nominal ΔP 1.69 psf vs. WC-135B). The vertical bars mark the 90% confidence limits of plotted data points. Listeners from communities of Fontana and Redlands – Phase II.

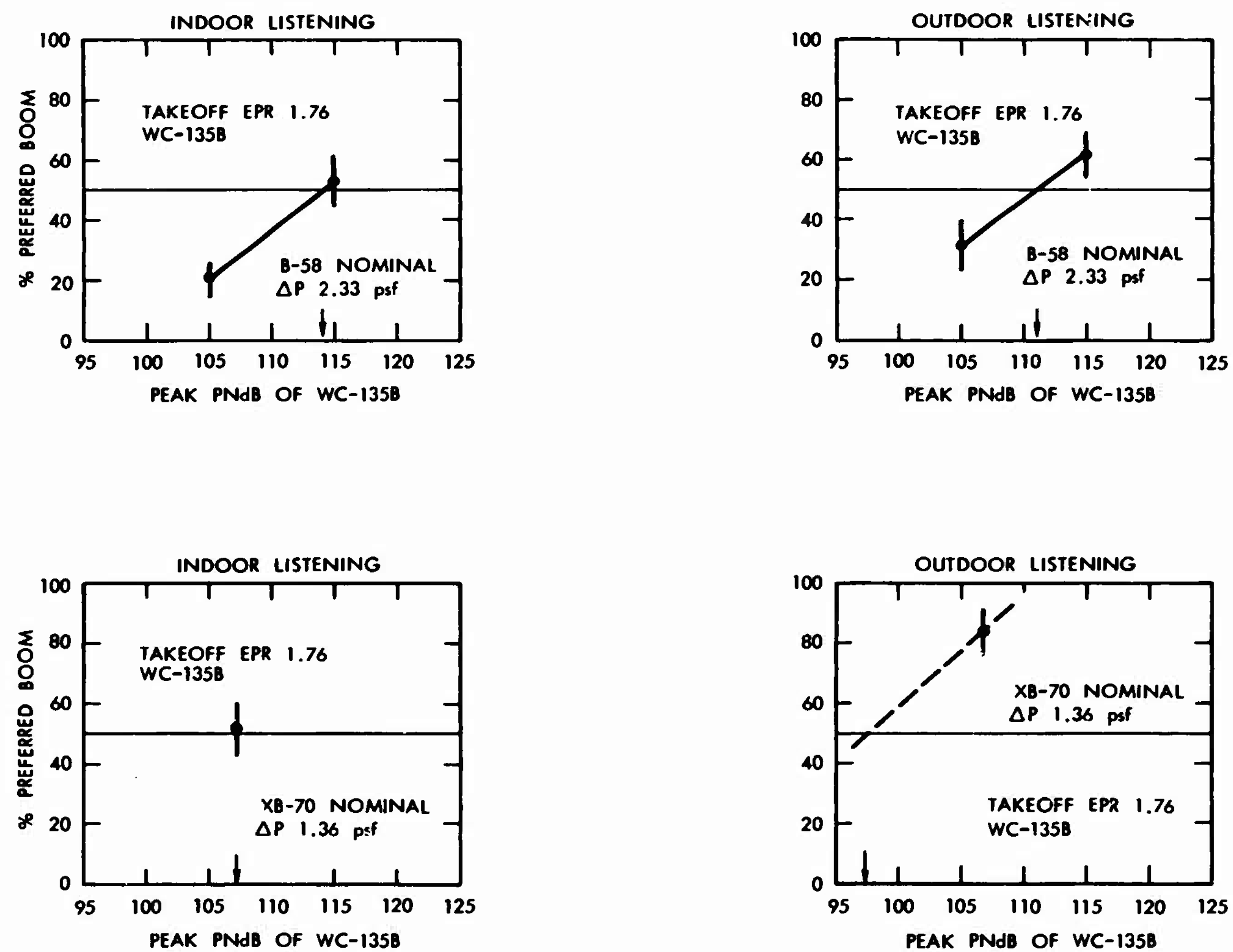


FIG. 4 RESULTS OF PAIRED–COMPARISON JUDGMENTS OF SONIC BOOM vs. SUBSONIC NOISE (B-58 nominal ΔP 2.33 psf vs. WC-135B and XB-70 nominal ΔP 1.36 psf vs. WC-135B). The vertical bars mark the 90% confidence limits of the plotted data points. Listeners from Edwards AF Base – Phase II.

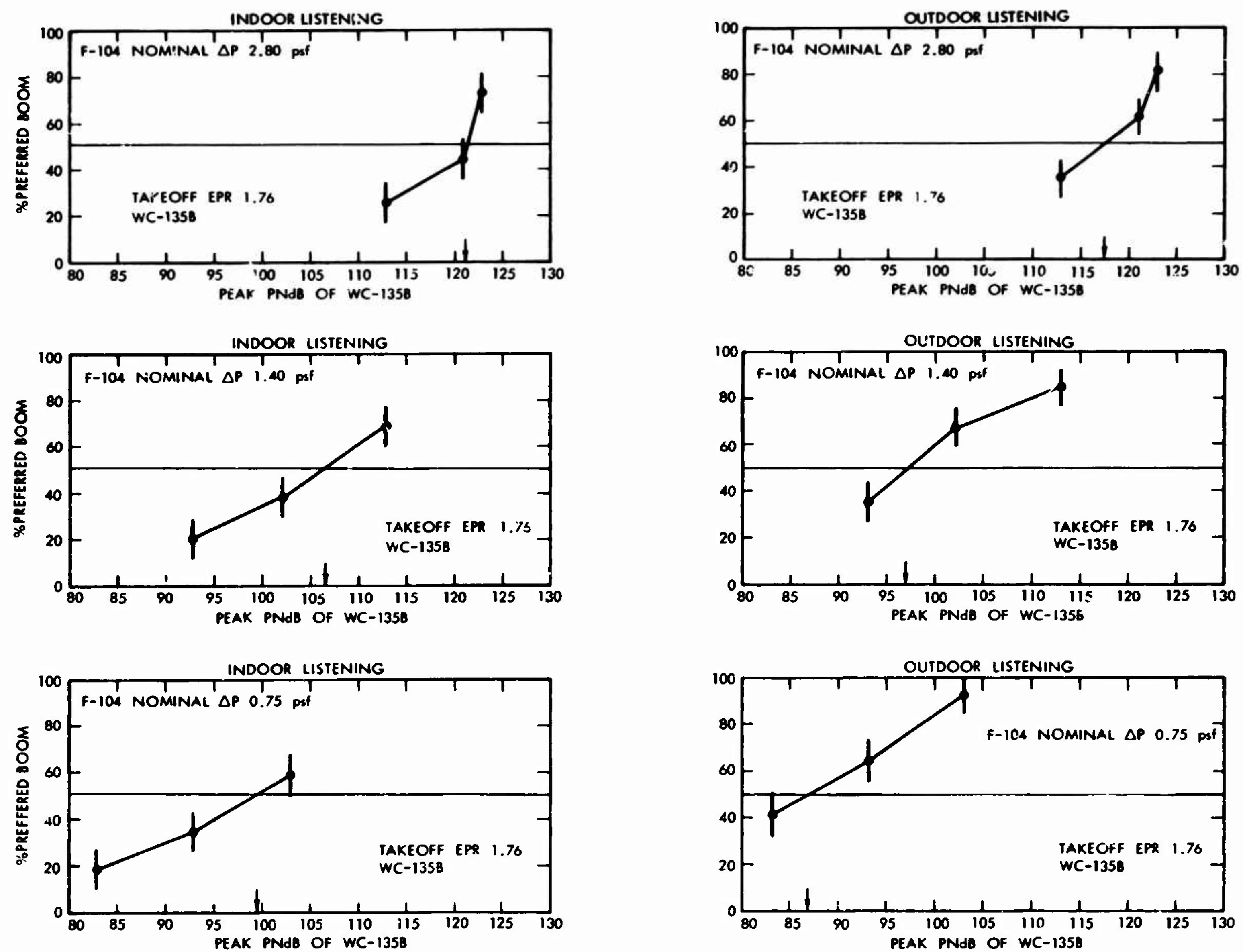


FIG. 5 RESULTS OF PAIRED-COMPARISON JUDGMENTS OF SONIC BOOM vs. SUBSONIC NOISE (F-104 nominal ΔP 0.75 psf, 1.40 psf, and 2.80 psf vs. WC-135B). The vertical bars mark the 90% confidence limits of plotted data points. Listeners from Edwards AF Base – Phase II.

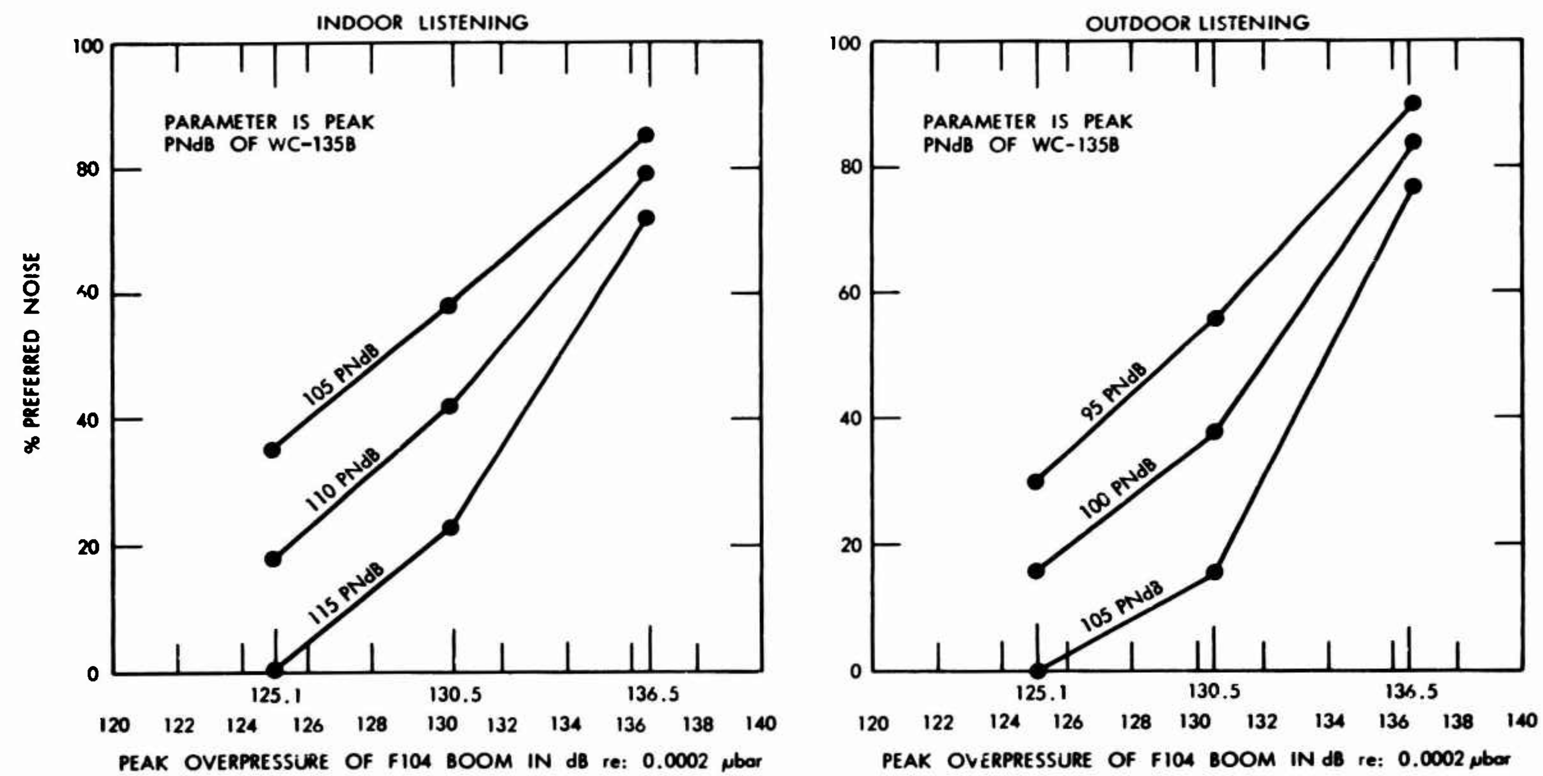


FIG. 6 RESULTS OF PAIRED-COMPARISON JUDGMENTS OF F-104 SONIC BOOMS vs. SUBSONIC NOISE (Derived from Fig. 5)

Table 2

RESULTS OF PAIRED-COMPARISON JUDGMENTS OF RELATIVE ACCEPTABILITY OF SONIC BOOMS VS. SUBSONIC AIRCRAFT NOISE

NOTE - All overpressure and energy values for the sonic boom and PNdB levels for subsonic aircraft noise are for outdoor measurements

1	2	3	4		5		6		7	8
Variable	Subjects From	A/C	Nominal ΔP		Measured ΔP for N Missions-Median of the Medians of 5 Microphones Over N Missions[4]		Aircraft Noise when Judged Equal to Boom		Number of Subjects	N Missions-Number of Pairs of Booms vs. Noises
							Indoors	Outdoors		
Subjects from Different Communities	Edwards AF Base	+ B-58[1]	1.69 psf*	132.14 dB**	1.94 psf	133.34 dB	109 PNdB	105 PNdB	120	25
	Fontana	B-58[2]	1.69	132.14	1.74	132.39	119	111	98	12
	Redlands	B-58[2]	1.69	132.14	1.73	132.34	118	108	148	12
Different Types of Aircraft	Edwards AF Base	+ B-58[1]	1.69	132.14	1.94	133.34	109	105	120	25
		-F-104[2]	1.40	130.50	1.40	130.50	107 (108)[5]	97 (100)[5]	120	13
		XB-70[3]	1.36	130.25	1.35	130.19	107 (110)	98 (101)	120	4
Booms of Different Intensities From Same Aircraft		F-104[2]	0.75	125.08	0.86	126.27	99 (101)	87 (89)	120	12
		-F-104[2]	1.40	130.50	1.40	130.50	107 (108)	97 (100)	120	13
		F-104[2]	2.80	136.52	2.77	136.43	121 (120)	117 (116)	120	12
		+B-58[1]	1.69	132.14	1.94	133.34	109	105	120	25
		B-58[2]	2.33	134.93	2.56	135.74	114	111	120	20
		B-58	2.65	136.05	2.91	136.86	117	112	120	24

+ The data in these three lines are for the same missions.
- " " " " two " " " " " " "

1. Aircraft were flown on track 5 miles to one side of test facility.
2. Aircraft were flown directly over test facility.
3. Aircraft were flown on track 13 miles to one side of test facility.
4. The five microphones were arranged at the test facility in a cruciform with a spacing of 100 ft between microphones.
5. Values reported in a similar table in an Interim Report (July 1967) of the Edwards AF Base Study, if different than in the present table, are shown in parentheses. These changes are due to the availability for the present report of physical measurements of some of the aircraft noise not yet analyzed when the Interim Report was prepared.

* pounds per square foot (psf).

** $dB = 10 \log_{10} \frac{p_1^2}{p_o^2}$, and p_o is 0.0002 μbar (0.0002 dyne/cm^2), and p_1 is peak overpressure in bars (or dynes cm^2).

Table 2 (Continued)

9 A/C	10 Difference between Median Measured ΔP and Nominal ΔP (Col.4 minus Col.5)		11 Average Difference between Median of 5 Microphones for a Single Mission and Nominal ΔP*		12 Average Difference between Median of 5 Microphones for a Single Mission and Median Measured ΔP for N Missions**		13 Median Measured Duration	14 Median Measured Rise Time
+ B-58[1]	0.25 psf	1.20 dB	0.38 psf	1.75 dB	0.33 psf	0.71 dB	0.171 sec	0.007 sec
B-58[2]	0.05	0.25	0.23	1.17	0.22	1.30	0.183	0.006
B-58[2]	0.04	0.20	0.37	1.60	0.37	1.60	0.197	0.008
+ B-58[1]	0.25	1.20	0.38	1.75	0.33	0.71	0.171	0.007
- F-104[2]	0	0	0.22	1.38	0.22	1.38	0.079	0.005
XB-70[3]	0.01	0.06	0.15	0.88	0.15	0.88	0.277	0.006
F-104[2]	0.11	1.19	0.25	2.10	0.21	1.63	0.106	0.006
- F-104[2]	0	0	0.22	1.38	0.22	1.38	0.079	0.005
F-104[2]	0.03	0.09	0.37	1.08	0.27	1.08	0.080	0.005
+ B-58[1]	0.25	1.20	0.38	1.75	0.33	0.71	0.171	0.007
B-58[2]	0.23	0.81	0.40	1.28	0.33	1.01	0.160	0.005
B-58[1]	0.26	0.81	0.39	1.17	0.31	1.92	0.148	0.009

+ The data in these three lines are for the same missions.
- " " " " two " " " " " "

* $\frac{1}{N}\sum_{i=1}^{N}\left|X_i - \text{Nominal } \Delta P\right|$: where X_i is the median of 5 microphone measurements for the i^{th} mission, and N is number of missions.

** $\frac{1}{N}\sum_{i=1}^{N}\left|X_i - \text{Median } (X_i)\right|$: where X_i is the median of 5 microphone measurements for the i^{th} mission, and N is number of missions.

Table 2 (Concluded)

15 Subjects From	16 A/C	17 Nominal ΔP		18 Date	18 Mission Number	19 Phase
Edwards AF Base	+ B-58	1.69 psf	132.14 dB	+ 6 June	+71	
				7 June	45R; 46R; 49; 50	I
				8 June	41; 42; 43; 55R; 46R	
				9 June	41S; 42S; 43S; 46S; 56SR; 57SR	
				20 June	43; 54; 59	
				21 June	40; 48; 48; 60; 61; 68	
Fontana	B-58	1.69	132.14	8 Nov	22-32; 121	II
Redlands	B-58	1.69	132.14	8 Dec	122-132; 221	II
Edwards AF Base	+ B-58	1.69	132.14	+See Above	+See Above	I
	-F-104	1.40	130.50	-Var. Days	-61-72;172	II
	XB-70	1.36	130.25	Var. Days	5-8	II
	F-104	0.75	125.08	Var. Days	73-84	II
	-F-104	1.40	132.14	-See Above	-See Above	II
	F-104	2.80	136.52	Var. Days	49-60	II
	+ 58	1.69	132.14	+See Above	+See Above	I
	B-58	2.33	134.93	Var. Days	33-48; 85-88	I
	B-58	2.65	136.05	6 June	74	
				7 June	76R; 77R; 79; 80	
				8 June	72; 73, 75; 80R; 86R; 87R	
				9 June	72S; 73S; 75S; 80SR; 86SR; 87SR	
				20 June	84; 93	
				21 June	85; 89; 99; 100; 101	

\+ The data for this B-58 flight condition are for the same missions.

\- The data for this F-104 flight condition are for the same missions.

Table 3

SHOWING VALUES OF AIRCRAFT NOISE WHEN SUBJECTIVELY EQUAL TO F-104 SONIC BOOM
IN VARIOUS UNITS SOMETIMES USED FOR MEASURING AIRCRAFT NOISE

Subjects	Nominal ΔP		Nominal	Measured Subsonic Aircraft Noise Where the Noise is Judged Equal to the F-104 Sonic Boom										
	psf	dB*	$E_{0.5}$PNdB†	Peak dB(A)	Peak dB(B)	Peak dB(C)	Peak dB(N)	Peak Phons	Peak PNdB	Peak $PNdB_t$	$E_{0.5}$PNdB	$E_{0.5}PNdB_t$	E_{15}PNdB	$E_{15}PNdB_t$
Edwards Indoor	2.8	136.52	101	107	106	109	121	120	121	122	125	127	110	112
↓	1.4	130.50	96	93	96	98	105	104	107	108	116	118	101	103
	0.75	125.08	90	86	91	94	98	97	99	99	111	112	96	97
Edwards Outdoor	2.8	136.52	101	102	105	106	116	115	117	119	123	125	108	110
↓	1.4	130.50	96	85	89	90	96	95	97	97	110	110	95	95
	0.76	125.08	90	74	80	83	86	87	87	87	101	102	86	87

* re 0.0002 μbar.

† PNdB calculated from nominal spectrum of boom from F-104 with a rise time of 0.005 seconds, a duration of 0.085 seconds and the given peak overpressures.

caused, as noted in Table 2, some slight changes in some of the relations between the sonic booms and the calculated perceived noise levels of the aircraft noise. The differences between these relations reported in the Interim Report and this Final Report are illustrated for the F-104 in Fig. 7.

The vertical lines drawn through each data point on Figs. 1 through 5 represent the 90 percent probability ranges for the data points; the ranges are based on the number of subjects involved and the percentage value of each point.[5] The plotted points represent the average percent of the subjects who preferred the boom on each of the two boom vs. noise and two noise vs. boom pairs.

It is to be noticed that some of the data points obtained with the Fontana and Redlands subjects and with the XB-70 tests with Edwards subjects were such that for three conditions (Fontana subjects listening indoors, Redlands subjects listening outdoors, and Edwards subjects listening outdoors to XB-70 tests) it was necessary to extrapolate a curve beyond a data point for the curve to cross the 50 percent line from the ordinate.

In the case of the Fontana subjects, the reason for this problem was that the intensity levels of the noises to be judged against the sonic boom from the B-58 were planned on the basis of some of the results obtained with the Edwards subjects. As it turned out, the Fontana subjects found the boom so much more unacceptable, relative to the aircraft noise, than had the Edwards subjects that the data points for the indoor listeners were somewhat lower than desired.

The number of flights available from the XB-70 aircraft and the frequency with which the aircraft could be operated (about one flight per week) made it impractical to perform as many tests with the XB-70 as with the B-58 and F-104 aircraft. Accordingly, for comparison tests of the noise from the subsonic aircraft with the XB-70 boom, the XB-70 was operated to provide four booms at an intensity (nominal 1.36 psf) that was estimated, on the basis of the other judgment tests, to be about as equally acceptable when heard indoors as the noise from the subsonic

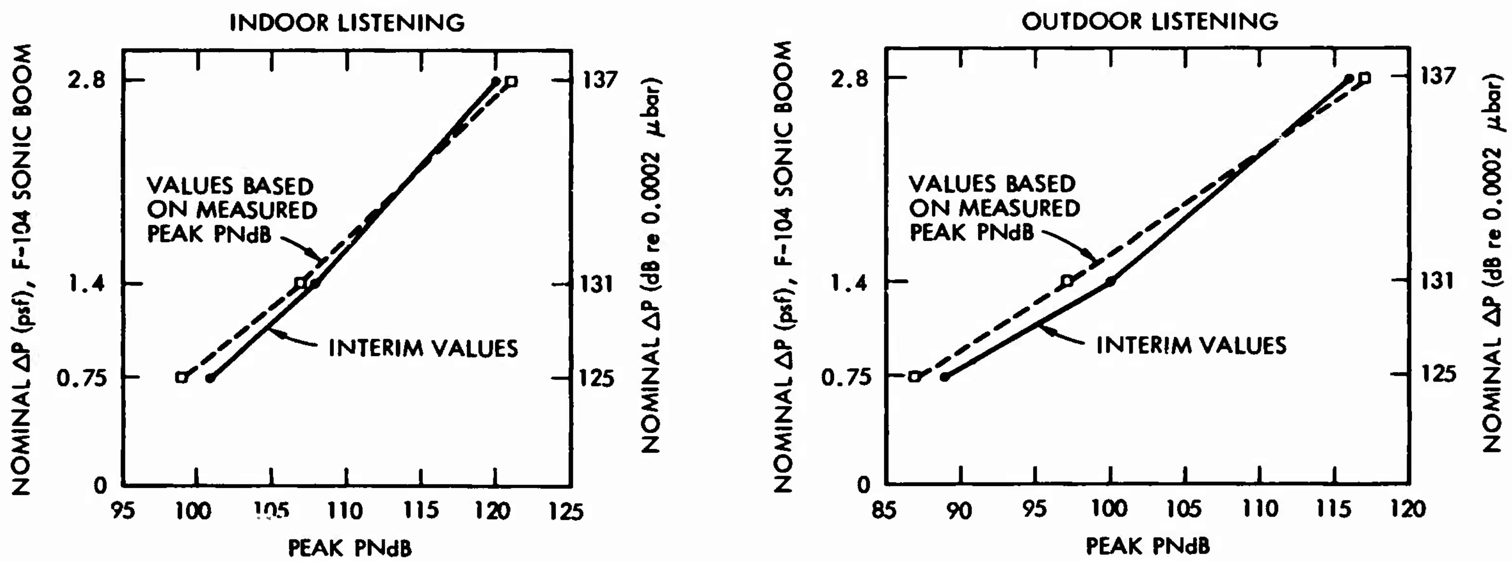


FIG. 7 SHOWING DIFFERENCES BETWEEN RESULTS REPORTED FOR F-104 vs. AIRCRAFT NOISE IN INTERIM REPORT (July 1967) AND PRESENT FINAL REPORT. Data obtained from Table 2.

aircraft at about 107 PNdB. The extrapolation required of the data for the outdoor listeners was based on the general shape of the curves drawn in Figs. 1 through 5. By this means it was possible to obtain comparative results of the acceptability, relative to the noise from the subsonic aircraft, of the booms from the F-104, B-58, and XB-70 with a minimum number of flights required of the XB-70 aircraft. To achieve this nominal boom intensity from the XB-70, it was necessary that its flight track be offset from the normal track by 13 miles.

The nominal peak overpressures were calculated by engineers from the Langley Research Center of the National Aeronautics and Space Administration (NASA). The theory used herein for the calculation of the nominal peak overpressures takes into account, relative to the generation and propagation of sonic booms, the volume and lift components of the aircraft, temperature, pressure, and density changes in the atmosphere which have some influence on boom propagation along the boom path, and effects of near-field signature characteristics. The nominal peak overpressures for supersonic aircraft agrees within less than 1 dB on the average with actual measured peak overpressures (see Col. 10, Table 2). It is perhaps of interest to also note that while the median peak overpressure of five microphones spaced within 100 feet of each other in a cruciform array was, on the average, less than 1 dB from the nominal theoretical value, the variation in peak overpressure among points within that space was, on the average, about 1.5 dB (see Col. 11, Table 2). This "fuzziness" in the peak overpressure is found within distances of but a few feet and is apparently due to normal low altitude atmospheric turbulence.

The PNdB values for the noise from the subsonic aircraft were determined from spectral analyses of recordings made outdoors at the test site. Figures 8 and 9, and Table 4 give various measured PNdB levels as a function of altitude for a number of flights of the subsonic aircraft. It is to be noted that the noise from a given subsonic aircraft flying at a given altitude and power setting does not seem to show quite as much variation for repeated flights as does the sonic boom (an average deviation usually of about 1.0 dB, from Table 4 vs. 1.5 dB from Col. 12, Table 2).

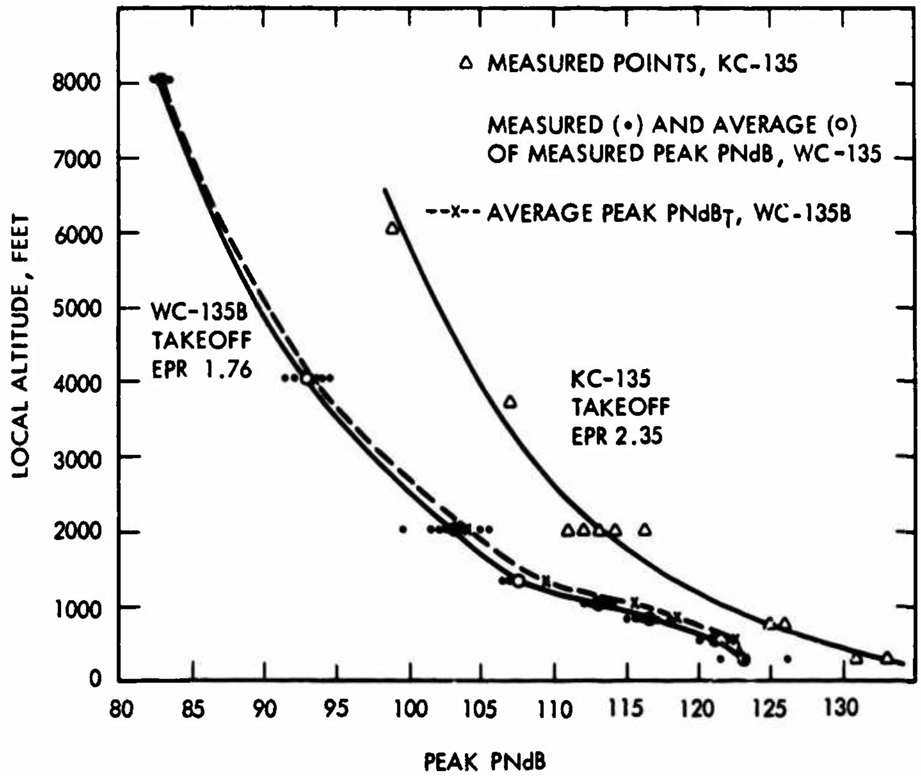


FIG. 8 ALTITUDE OF AIRCRAFT PLOTTED AGAINST MEASURED AND AVERAGE PEAK PNdB (KC-135 and WC-135B) AND PNdB$_T$ (WC-135B) VALUES. Aircraft using takeoff engine power.

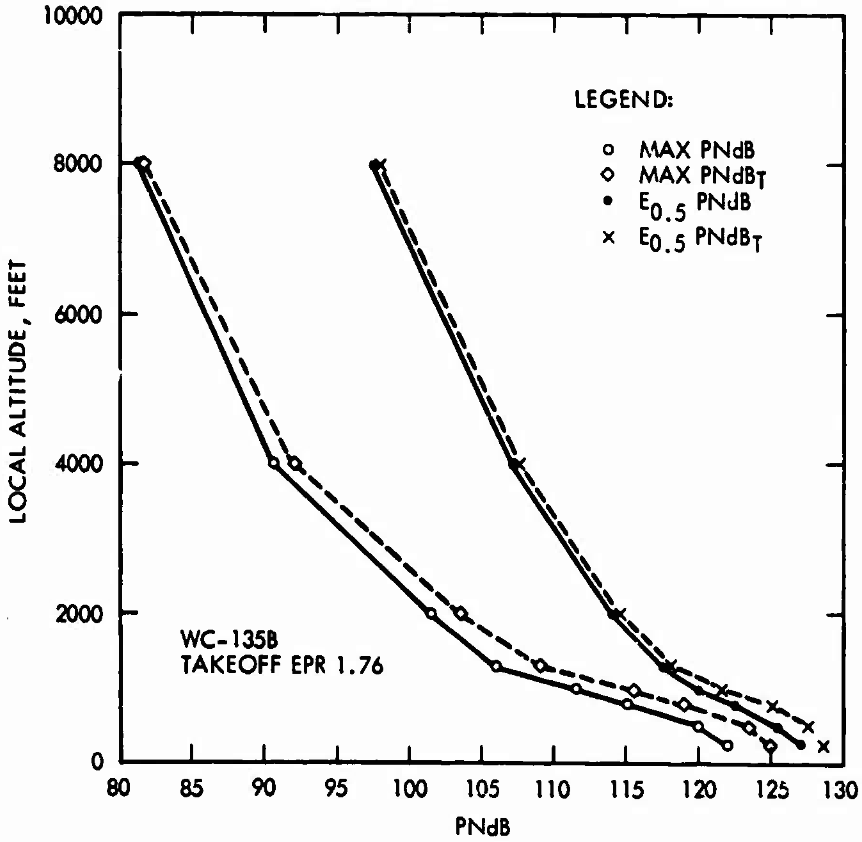


FIG. 9 ALTITUDE OF AIRCRAFT PLOTTED AGAINST MEASURED MAX PNdB AND $E_{0.5}$ PNdB FOR WC-135B USING TAKEOFF POWER

Table 4

AVERAGE VALUES OF PEAK PNdB, PEAK $PNdB_t$, MAX PNdB, MAX $PNdB_t$, $E_{0.5}PNdB$, $E_{0.5}PNdB_t$ AND TONE CORRECTION FOR SEVERAL ALTITUDE AND AIRCRAFT CONDITIONS

Altitude (local altitude in feet)	Aircraft	EPR	Number of Missions	Peak PNdB		Peak $PNdB_t$		Avg. Value of Tone Correction	Max. PNdB		Max. $PNdB_t$		Avg. Value of Tone Correction	$E_{0.5}PNdB$*		$E_{0.5}PNdB_t$*		Avg. Value of Tone Correction
				Avg.	Avg. Dev.	Avg.	Avg. Dev.		Avg.	Avg. Dev.	Avg.	Avg. Dev.		Avg.	Avg. Dev.	Avg.	Avg. Dev.	
8000	WC-135B	Takeoff (1.76)	2	83.0	0.5	83.0	0.5	0	81.4	0.1	81.7	0.3	0.3	97.6	0.0	98.0	0.1	0.4
4000			7	92.8	1.1	93.4	1.1	0.6	90.6	1.1	92.1	1.2	1.5	107.2	0.9	107.5	0.9	0.3
2000			17	102.8	1.1	104.1	2.0	1.3	100.8	1.1	103.4	2.0	2.6	113.8	0.7	114.7	0.9	0.9
1300			3	107.4	1.3	109.4	1.7	2.0	105.8	1.3	108.9	1.7	3.1	117.4	1.8	118.2	1.6	0.8
1000			6	112.9	0.5	115.7	1.3	2.8	111.4	0.6	115.5	1.0	4.1	119.9	0.8	121.7	1.0	1.8
800†			12	116.4	0.6	118.3	1.7	1.9	114.9	0.7	118.8	0.6	3.9	122.5	0.4	124.8	0.3	2.3
500†			4	120.8	0.7	122.4	1.4	1.6	119.8	0.6	123.4	0.6	3.6	125.3	1.0	127.4	1.0	2.1
250†			3	123.0	1.9	123.0	1.9	0	122.2	1.7	124.8	2.0	2.6	127.1	1.8	128.5	1.5	1.4
1500	WC-135B	Landing (1.3)	4	105.8	1.2	112.5	1.6	6.7	104.1	1.9	111.7	1.8	7.6	110.4	1.1	115.9	1.5	5.5
750†			4	114.3	0.7	117.6	3.0	3.3	113.1	0.8	120.0	1.2	6.9	119.1	0.7	125.2	0.7	6.1
250†			4	122.4	1.2	123.9	1.3	1.5	121.1	1.4	125.7	1.1	4.6	124.7	1.1	129.6	1.8	4.9
2000	KC-135	Takeoff (2.35)	12	111.1	0.6	111.2	0.7	0.1	108.8	1.1	109.9	1.0	1.1	116.4	1.5	117.9	0.8	1.5
800	KC-135	Landing (1.5)	12	108.1	0.6	108.5	1.0	0.4	106.3	0.7	107.5	1.1	1.2	114.0	0.7	115.3	0.8	1.3

* For the WC-135B takeoff condition, the Max PNdB and Max $PNdB_t$ values are integrated over the duration defined as the time period in which the values are within 20 dB of the maximum value. For the other conditions, the Max PNdB and Max $PNdB_t$ values are integrated over the duration defined as the time period in which the values are within 10 dB of the maximum value.

† By definition, Peak PNdB is always greater than or equal to Max PNdB (averaging 1.7 dB greater for the above table). On the average, Peak $PNdB_t$ is greater than Max $PNdB_t$, averaging 0.3 dB greater for the above table. Peak $PNdB_t$ is not necessarily greater than Max $PNdB_t$; for the cases marked † Peak $PNdB_t$ is less than the average Max $PNdB_t$.

1. Relative Acceptability of Booms of Different Intensities

Figures 1 through 5 and Table 2 indicate that for indoor listening the noise from a subsonic aircraft (KC-135) at a level of 109 PNdB was about equally preferred to a sonic boom of a nominal 1.69 psf from a B-58. The results were about the same when the subsonic aircraft was operated with partial takeoff or landing engine power settings. It is interesting to note that for indoor listening when the nominal sonic boom overpressure was increased to 2.65 psf, the PNdB level of the noise from the KC-135 had to be approximately 117 PNdB to be judged as equally acceptable as the boom. This result would perhaps not be expected inasmuch as increasing the overpressure from 1.69 to 2.65 psf represents only a 4 dB increase in physical intensity, whereas, as judged against the noise from the KC-135, there appeared to be an effective increase in subjective noisiness of about 8 PNdB. Likewise, for indoor listening an overall increase of about 12 dB in the physical intensity of the boom from the F-104 (from 0.75 psf to 2.8 psf) required an increase of 22 PNdB in the aircraft noise to maintain equal acceptability of the two sounds.

These results would imply that the subjective objectionableness or noisiness of a sonic boom increases at a greater rate than does the noisiness of the sound from a subsonic jet aircraft when the intensity of the two sounds is increased by an equal amount. Broadbent and Robinson,[7] using a magnetic tape recording (played back via loudspeakers) made inside a structure overflown by a supersonic aircraft, found a somewhat similar but less dramatic difference between the growth (as a function of their intensities) of the unacceptability of sonic booms and aircraft noise.

2. Indoor vs. Outdoor Listening - Relative Judgments

It is clear that the boom heard outdoors is more acceptable relative to the noise of the subsonic jet aircraft (by an amount ranging from 3 to 12 PNdB) than when the two sounds are heard indoors. That the results between the relative judgments indoors and outdoors should be even this similar is perhaps fortuitous in that the nature of the two sounds is so different outdoors and because the sounds, due to attenuation by

the house and vibrations present indoors, further differ from their outdoor counterparts. Apparently, however, the secondary sounds or "rattles" introduced by the nonlinear response of components of the house to the boom contribute substantially to the subjective acceptability of the boom heard indoors. The relation between house response and subjective ratings as a function of wall displacement of some of the test rooms in response to sonic booms will be discussed below in Section G.

It might be noted that in a previous laboratory test by Pearsons and Kryter[23] of the relative acceptability of recorded subsonic aircraft noise and a simulated "indoor" boom, a boom which would measure 1.69 psf outdoors would be judged to be equal to the noise of a subsonic jet at 113 PNdB measured outdoors. Data obtained by Broadbent and Robinson, using, as aforementioned, a sonic boom and aircraft noise recorded indoors and played back over loudspeakers to listeners, indicate that a 1.69 psf boom would be judged as equally acceptable as an aircraft noise of about 107 to 113 PNdB. These results, we believe, compare well with 109 PNdB noise and nominal 1.69 psf booms found in the present study with actual aircraft to be equal subjectively when heard indoors.

3. Indoor vs. Outdoor Listening - Rating Scale

The scores on the acceptability rating scales (see Table 5) demonstrate that the booms heard indoors were on the average slightly more acceptable than the same booms as heard by the subjects outdoors--about 34 percent of the indoor subjects rated the booms as unacceptable when about 47 percent of the outdoor subjects rated the same booms as unacceptable. The noise of the subsonic jet was also rated more acceptable indoors than it was when heard outdoors, but by a slightly larger amount--41 percent vs. 23 percent. Inasmuch as the house structure should attenuate the aircraft noise somewhat more than sonic boom (the major energy in the boom is at lower frequencies where the attenuation of the sound by the house is less than it is for the frequency region occupied by the aircraft noise), it might be expected on first thought that the booms and noise would be much more acceptable indoors than outdoors. The relatively small improvement in the acceptability of the booms and aircraft noise, by virtue of the listeners being indoors and therefore somewhat sheltered

from the sound, has been found to be true in previous studies of road traffic and aircraft noise.[3,6,9,22]

4. Comparisons Among Subjects from Different Communities

Table 2 shows that the subjects from Redlands and Fontana judged the sonic boom from the B-58 relative to the subsonic aircraft noise in much the same way--a noise of 118-119 PNdB was judged equal to the boom at 1.69 psf when heard indoors and to 108-111 PNdB when heard outdoors. Thus, to these subjects the boom was much less acceptable than it was to the subjects from Edwards AF Base--equivalent to a 10 PNdB change in the noise from the subsonic aircraft when heard indoors and about 5 PNdB when heard outdoors. The difference between the judgments of the subjects from Edwards AF Base and those from the relatively "quiet" communities of Fontana and Redlands is illustrated by the extrapolated curves in Fig. 10. Also, Table 6 shows that on the average the subjects from Fontana and Redlands, combined, rated on the acceptability scale the aircraft noise and particularly the sonic booms as being more unacceptable than did the subjects from Edwards AF Base for comparable booms and noises.

An aircraft noise survey showed that the median peak level of aircraft noise in typical residential neighborhoods in Redlands was about 75 PNdB (maximum peak level of about 95 PNdB), and in Fontana about 85 PNdB (maximum peak level of about 100 PNdB); also, these communities were not under or near usual flight tracks for supersonic military aircraft involved in training or test missions.

An aircraft noise survey of the residential area of Edwards AF Base revealed that subsonic aircraft noise reached occasional peak levels of 110 PNdB; this area, however, was subjected to about four to eight booms per day for the past three years at a median nominal peak overpressure of 1.2 psf (see Table 7 and Fig. 11). The subjects had lived on Edwards AF Base an average of two years.

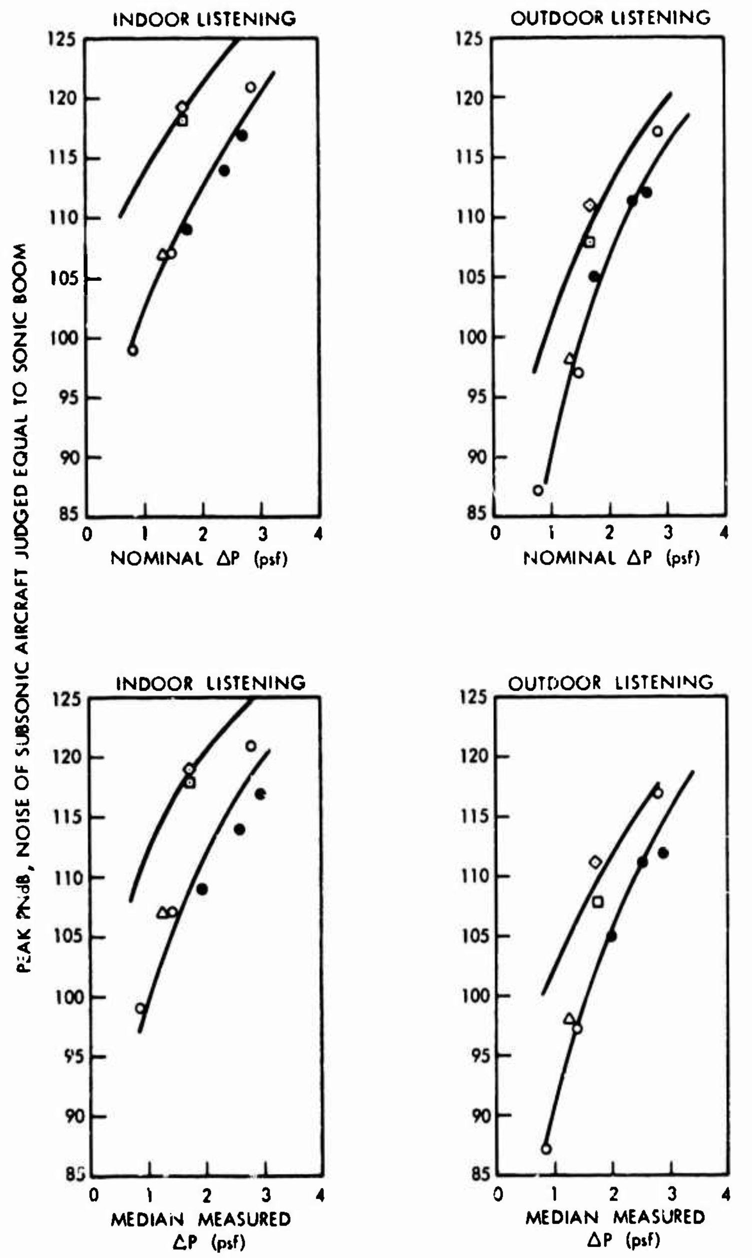
It is to be noted on Table 1 that the subjects from Redlands and Fontana were, on the average, somewhat older than those from Edwards AF Base. As a check on the importance of age to the relative judgment of the sonic boom vs. the aircraft noise, the data were divided for the

Table 5

PERCENTAGE OF PERSONS WHO RATED SONIC BOOMS AND NOISES AS UNACCEPTABLE (LESS THAN JUST ACCEPTABLE) LISTENERS FROM EDWARDS AIR FORCE BASE

SOURCES OF BOOMS AND NOISES						LOCATIONS OF PERSONS										
A/C	Nom. Peak Overpressure (psf)	Alt.	EPR	PNdB	Number of Missions*	Out-door	Block-house**	E1&E2 In-door	E1-BR	E1-LR	E1-FK	E2-BR	E2-LR	E2-DR	E2-FK
B-58	1.69				12	33%	23%	27%	15%	25%	17%	39%	46%	28%	24%
B-58	2.06				4	51	--	37	42	68	20	11	28	73	54
B-58	2.33				11	63	--	28	34	44	6	13	51	38	39
B-58	2.52				2	64	--	49	41	67	32	18	83	92	40
B-58	2.65				8	68	55	62	32	70	52	89	73	56	59
	Av. 2.25					Av. 56	--	41	33	55	25	34	56	57	43
F-104	0.70				6	2	--	2	6	0	1	0	0	3	3
F-104	1.36				2	17	--	3	7	0	4	0	0	9	0
F-104	1.40				6	30	--	16	16	12	9	11	9	51	15
F-104	1.50				4	29	--	27	10	29	23	54	43	4	22
F-104	1.69				1	75	--	29	43	38	0	11	22	67	38
F-104	2.00				2	33	--	31	0	7	17	75	57	0	39
F-104	2.80				7	74	--	63	54	50	22	62	89	100	73
F-104	3.30				2	98	--	82	63	75	79	100	79	50	100
	Av. 1.83					Av. 45	--	32	25	26	19	39	36	36	36
XB-70	1.36				2	21	--	28	32	15	11	19	39	74	25
XB-70	2.06				4	53	--	25	33	32	9	6	21	68	27
XB-70	2.52				2	65	--	33	55	53	18	10	39	67	28
	Av. 1.98					Av. 46	--	29	40	33	13	12	33	70	27
WC-135B		8000	1.76	85	2	1	--	1	0	0	4	0	0	9	0
KC-135		3000	1.5	95	4	2	5	2	0	0	2	3	0	0	3
WC-135B		4000	1.76	95	4	3	---	2	7	0	0	0	0	0	2
WC-135B		2000	1.76	105	9	24	--	11	17	11	5	4	4	17	14
KC-135		1000	1.5	107	4	28	33	22	6	30	21	15	16	11	38
WC-135B		1300	1.76	110	2	41	--	14	0	0	27	5	0	44	15
WC-135B		1000	1.76	113	3	70	--	35	25	50	22	33	15	65	44
WC-135B		800	1.76	115	6	77	--	43	44	56	19	47	24	55	49
KC-135		500	1.5	115	2	80	62	49	19	80	50	80	13	33	59
WC-135B		500	1.76	119	2	92	--	51	38	71	40	53	34	91	52
WC-135B		250	1.76	125	2	94	--	70	53	85	54	78	58	90	81
				Av. 111		Av. 47	--	27	19	35	22	29	15	38	32
Number of Persons per Mission						40-48	9-11	51-70	6-8	5-8	8-11	8-10	6-9	5-6	13-18

*The ratings are only for the first aircraft of a pair.
**Used in Phase I only.



BOUNDARY	CODE	SONIC BOOM A/C	SUBJECTS
UPPER	◇	B-58	FONTANA
	□	B-58	REDLANDS
LOWER	△	XB-70	EDWARDS
	○	F-104	
	●	B-58	

FIG. 10 RESULTS OF PAIRED COMPARISON JUDGMENTS FOR SUBJECTS FROM DIFFERENT COMMUNITIES. Data obtained from Table 2.

Table 6

PERCENTAGE OF PERSONS WHO RATED SONIC BOOMS AND NOISES AS UNACCEPTABLE (LESS THAN JUST ACCEPTABLE) LISTENERS FROM FONTANA AND REDLANDS

	SOURCES OF BOOMS AND NOISES						LOCATION OF PERSONS								
Group	A/C	Nom. Peak Overpressure (psf)	Alt.	EPR	PNdB	Number of Missions*	Out-door	In-door	E1-BR	E1-LR	E1-FK	E2-BR	E2-LR	E2-DR	E2-FK
Fontana	B-58	1.69				6	53%	50%	53%	71%	31%	69%	15%	27%	66%
	WC-135B		2800	1.76	100	2	5	1	7	0	0	0	0	0	0
	WC-135B		1400	1.76	109	2	33	1	0	0	0	6	0	0	0
	WC-135B		700	1.76	116	2	86	30	44	44	15	45	7	30	30
					Av. 108		Av. 41	11	17	15	5	17	2	10	10
Redlands	B-58	1.69				6	25	29	9	22	17	33	36	50	40
	WC-135B		1800	1.76	103	2	31	4	0	7	0	0	19	0	4
	WC-135B		1000	1.76	110	2	69	15	0	7	8	22	13	20	27
	WC-135B		400	1.76	120	2	90	33	15	28	19	56	47	50	27
					Av. 111		Av. 63	17	5	14	9	26	26	23	19
Fontana & Redlands Combined	B-58	1.69					Av. 39	40	31	47	24	51	26	39	53
	WC-135B				Av. 110		Av. 52	14	11	15	7	22	14	22	15
	Number of Persons Per Mission - Fontana						35	63	8	8	10	9	8	5	15
	Number of Persons Per Mission - Redlands						86	66	7	8	13	9	8	6	15

* The ratings are only for the first aircraft of a pair.

Table 7

USE OF EDWARDS AIR FORCE BASE SUPERSONIC CORRIDOR
Number of Sonic Booms

1963-1966

MONTH	1963	1964	1965	1966
January	---	161	126	193
February	4	110	102	165
March	11	140	97	287
April	106	162	48	257
May	190	104	109	107
June	139	137	86	289
July	179	82	107	
August	142	58	78	
September	149	54	203	
October	125	60	176	
November	108	65	41	
December	143	56	143	
Total:	1296	1189	1316	1298
Daily Average:	3.9	3.3	3.6	7.2

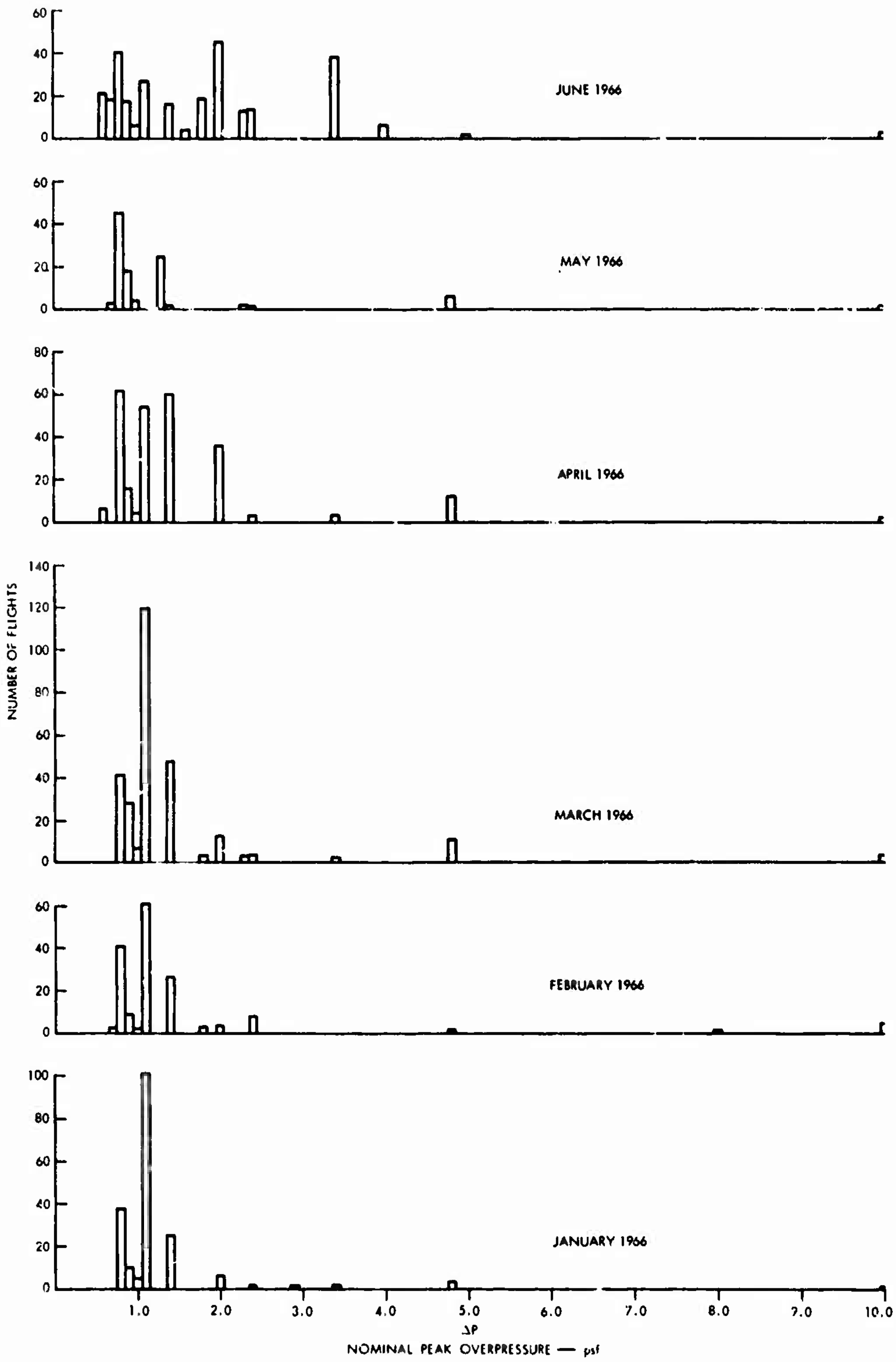


FIG. 11 HISTOGRAM OF NUMBER OF SUPERSONIC FLIGHTS OVER EDWARDS AF BASE PLOTTED AGAINST THE NOMINAL PEAK OVERPRESSURES OF THE BOOMS

Redlands subjects into two parts--those for the subjects above the median age, and those for the subjects below the median age. It was found that the results for these two subgroups of subjects agreed within 1 PNdB of the findings for the total group (see Table 8). Table 9 shows that age and sex were not consistently related to the acceptability rating scores given to sonic booms and the noise from subsonic aircraft.

It is presumed that the lesser acceptability of sonic booms to the subjects from Fontana and Redlands than to the subjects from Edwards AF Base may be due to the "adaptation" to the sonic booms enjoyed by the Edwards subjects as the result of an average of two year's previous exposure to sonic booms. It was also found, as will be described more fully later, that the residents of Edwards AF Base, in reply to an attitude survey, in general believed that their exposure to sonic booms at Edwards made them more tolerant of the boom.

B. <u>Sonic Booms vs. Sonic Booms</u>

A number of tests were conducted in which the subjects judged the relative acceptability of sonic booms from different supersonic aircraft or from the same type of supersonic aircraft flying in accordance with different or the same operational procedures. The results of these tests are given in Fig. 12 and 13. These tests do not show any consistent differences in the acceptability of one type of sonic boom vs. another type of those tested.

Of particular interest is the rate at which the percent preference score changed as a function of a change in peak overpressure. Figures 12 and 13 show that a change of 1.5 dB (about 0.3 psf at the boom intensity of 1.69 psf) for people indoors and 1.0 dB for people outdoors can cause an increase of about 12.5 percentage points in the number of people who judge the more intense boom to be less acceptable. This finding indicates that the subjective unacceptability of the sonic boom increases at a relatively rapid rate as its intensity level is increased, and at a somewhat more rapid rate for listeners outdoors compared with listeners indoors. It was noted that the rate of growth of unacceptability of the sonic boom appears to be greater than is the growth of unacceptability

Table 8

PERCENTAGE OF REDLANDS SUBJECTS (INDOOR LISTENERS) WHO PREFER BOOM (B-58 OF 1.69 PSF NOMINAL PEAK OVERPRESSURE)

Peak PNdB of WC-135B	Age Less than 50 Yrs. (Median 38 Years)	Age Greater than or Equal to 50 Years (Median 65 Years)
103	9%	26%
110	17	27
120	58	53
118	50	--
119	--	50

Table 9

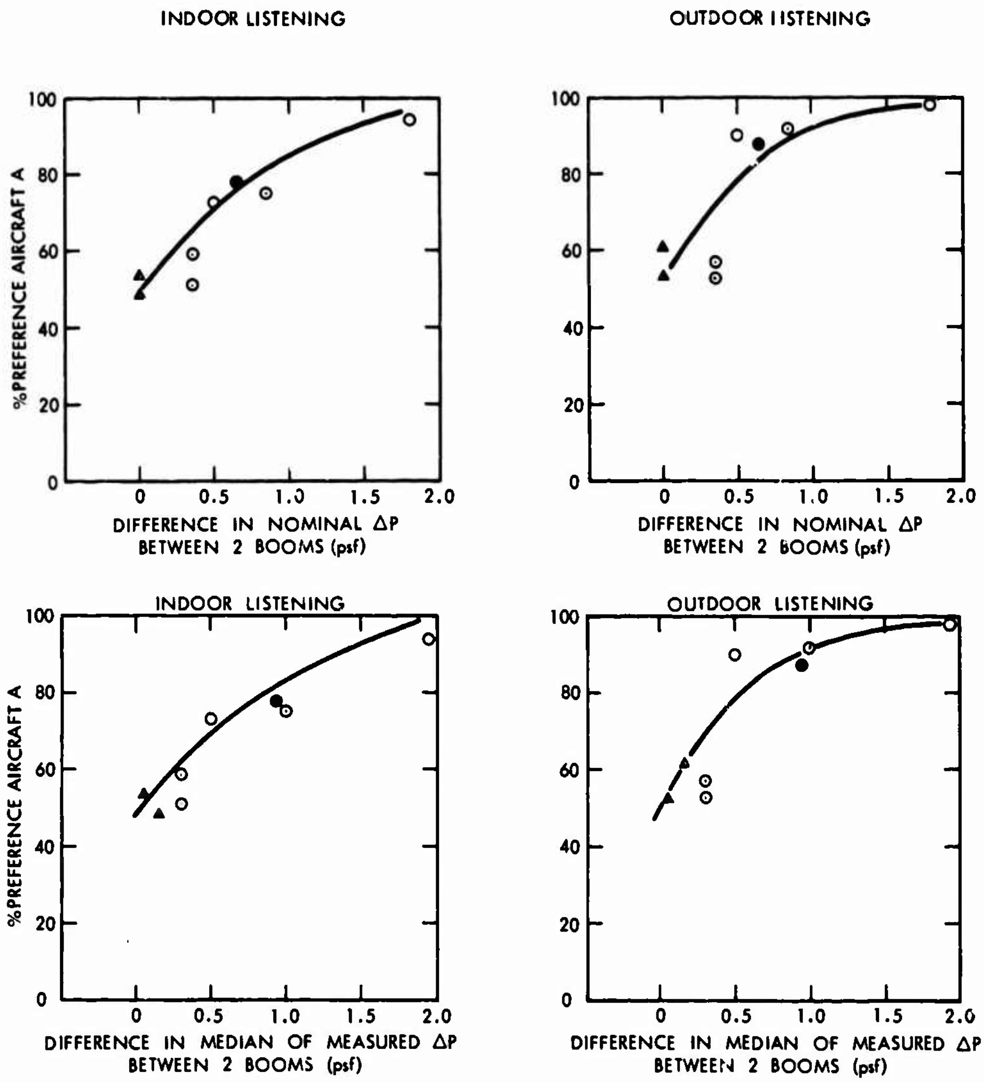
COMPARISON BY AGE AND SEX OF THE PERSONS WHO RATED SONIC BOOMS AND NOISE AS UNACCEPTABLE (LESS THAN JUST ACCEPTABLE)

Group	Median Age	A/C	Number of Flights	Indoor Listening (See notes for explanation of column headings and cell entries) ML vs. MG	FL vs. FG	ML vs. FL	MG vs. FG	Outdoor Listening ML vs. MG	FL vs. FG	ML vs. FL	MG vs. FG	Critical Value at 10% Level of Significance	Decision
Redlands	49	B-58	6	4/10 5/20 0.71	6/17 4/16 0.41	4/10 6/17 0.06	5/20 4/16 0.10	4/15 3/17 0.38*	8/28 3/14 0.25	4/15 8/28 0.02	3/17 3/14 0.07*	2.71	No Significant Difference in the Ratings
		WC-135B	6	2/10 3/20 0.12*	4/17 2/16 0.67*	2/10 4/17 0.05*	3/20 2/16 0.05*	10/15 11/17 0.01	19/28 10/14 0.06	10/15 19/28 0.01	11/17 10/14 0.16	2.71	
Fontana	38	B-58	6	2/5 3/9 0.06*	14/22 11/25 1.81	2/5 14/22 0.94*	3/9 11/25 0.31	1/2 2/6 0.20*	9/14 6/12 0.54	1/2 9/14 0.15*	2/6 6/12 0.45*	2.71	
		WC-135B	6	1/5 0/9 1.94*	4/22 2/25 1.09*	1/5 4/22 0.00*	0/9 2/25 0.77*	1/2 2/6 0.18*	6/14 5/12 0.00	1/2 6/14 0.04*	2/6 5/12 0.12*	2.71	
Edwards AF Base	32	B-58	9	2/5 3/7 0.01*	5/23 9/26 0.99	2/5 5/23 0.73*	3/7 9/26 0.16*	1/4 1/3 0.06*	8/19 5/21 1.52	1/4 8/19 0.41*	1/3 5/21 0.13*	2.71	
		KC-135	12	1/6 1/7 0.01*	5/25 4/26 0.19	1/6 5/25 0.03*	1/7 4/26 0.01*	1/4 1/3 0.06*	4/20 5/21 0.09	1/4 4/20 0.05*	1/3 5/21 0.13*	2.71	

* Inadequate sample size

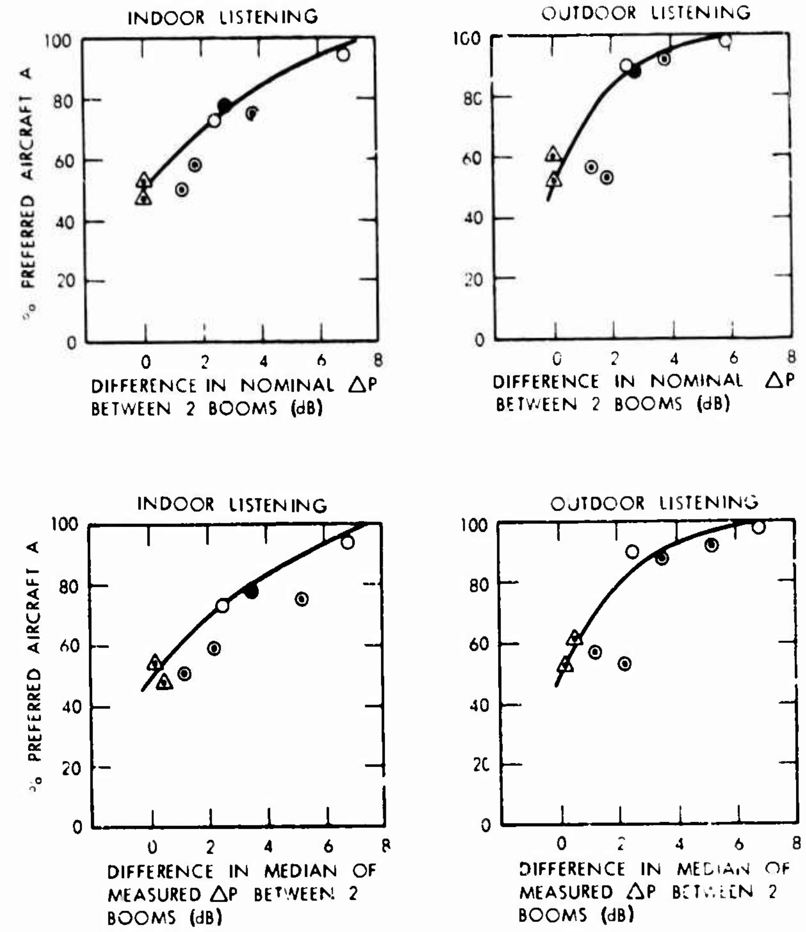
NOTES:

1. The comparisons are based on ratings for the first aircraft of a pair.
2. Symbols for age and sex classification: ML = males whose age is less than the median age; FL = females whose age is less than the median age; MG = Males whose age is greater than or equal to the median age; FG = females whose age is greater than or equal to the median age.
3. Differences in the ratings due to age are tested in the columns headed ML vs. MG and FL vs. FG. Differences in the ratings due to sex are tested in the columns headed ML vs. FL and MG vs. FG.
4. Cell entries: Upper left (or upper right) is a/a+b (or c/c+d) where a (or c) is the average number of unacceptable ratings and b (or d) is the average number of acceptable ratings for the designated class. (a+b (or c+d) is the average number of persons in the class.) The lower entry is the value of the test statistic: $\chi^2 = \frac{(ad - bc)^2(a+b+c+d)}{(a+b)(a+c)(b+d)(c+d)}$. Example: Third row and second column, a = 14, b = 8, c = 11, d = 14; $\chi^2 = \frac{(14^2 - 11 \cdot 8)^2(47)}{(22)(25)(22)(25)} = 1.81$. The adequacy of the sample size depends on the values of a and c in addition to the values of a+b and c+d.
5. Significance test and decision rule: The data are used to determine whether the same percentage of unacceptable ratings occurs for two classes. The hypothesis that the ratings are the same would be rejected if the value of the test statistic equals or exceeds 2.71 at the 10% level of significance (i.e., the probability is 0.10 that the hypothesis is rejected when it is true).
6. Reference 5, Chapter XI, Analysis of Enumeration Data.



	AIRCRAFT A					AIRCRAFT B				
CODE	TYPE A/C	NOMINAL ΔP	MEDIAN OF MEASURED ΔP	%PREFERENCE INDOOR	%PREFERENCE OUTDOOR	TYPE A/C	NOMINAL ΔP	MEDIAN OF MEASURED ΔP	%PREFERENCE INDOOR	%PREFERENCE OUTDOOR
●	B-58	1.69	1.91	78%	88%	B-58	2.33	2.84	22%	12%
○	F-104	1.50	1.52	73	90	F-104	2.00	2.02	27	10
	F-104	1.50	1.63	94	98	F-104	3.30	3.56	6	2
⊙	F-104	2.00	2.09	51	57	B-58	2.33	2.40	49	43
	F-104	1.36	1.14	59	53	B-58	1.69	1.46	41	47
	F-104	1.50	1.20	75	92	B-58	2.33	2.18	25	8
▲	XB-70	2.06	2.18	48	61	B-58	2.06	2.33	52	39
	XB-70	2.52	2.49	54	53	B-58	2.52	2.55	46	47

FIG. 12 RESULTS OF PAIRED-COMPARISON JUDGMENTS OF SONIC BOOMS (of the same type aircraft or two different types of aircraft) AT THE SAME AND AT DIFFERENT NOMINAL PEAK OVERPRESSURES IN psf. Listeners from Edwards AF Base.



AIRCRAFT A						AIRCRAFT B				
CODE	TYPE A/C	NOMINAL ΔP*	MEDIAN OF MEASURED ΔP*	% PREFERENCE		TYPE A/C	NOMINAL ΔP*	MEDIAN OF MEASURED ΔP*	% PREFERENCE	
				INDOOR	OUTDOOR				INDOOR	OUTDOOR
●	B-58	132.1	133.2	78	88	B-58	134.9	136.7	72	12
○	F-104 F-104	131.1 131.1	131.2 131.8	73 94	90 98	F-104 F-104	133.6 138.0	133.7 138.6	27 6	10 2
⊙	F-104 F-104 F-104	133.6 130.3 131.1	134.0 123.7 129.2	51 59 75	57 53 92	B-58 B-58 B-58	134.9 132.1 134.9	135.2 130.9 134.4	49 41 25	43 47 8
▲	XB-70 XB-70	133.9 135.6	134.4 135.5	48 54	61 53	B-58 B-58	133.9 135.6	134.9 135.7	52 46	39 47

*IN dB re 0.0002 μbar

FIG. 13 RESULTS OF PAIRED-COMPARISON JUDGMENTS OF SONIC BOOMS (of the same type aircraft or two different types of aircraft) AT THE SAME AND AT DIFFERENT NOMINAL PEAK OVERPRESSURES IN dB. Listeners from Edwards AF Base.

of the noise from subsonic aircraft (a 6 dB increase in the intensity of the sonic boom was found to be equivalent to a 12 PNdB increase in the level of a noise from a subsonic aircraft of equal acceptability).

C. Ratings of Sonic Booms

Comparisons can be made between the sonic booms from the F-104, B-58, and XB-70 aircraft on the basis of the scores obtained on the absolute rating scale. Figures 14 and 15 show the results obtained from the ratings given to sonic booms of different nominal and measured peak overpressures from the various aircraft when the particular booms occurred first in a pair for a given mission. (It was necessary to use only the results from the given position in a pair in order to avoid any biases due to the order in which the sounds were presented to the subjects.) On this measure the difference in the unacceptability of the booms from the various aircraft is rather small, if at all present. However, Figs. 14 and 15 show that the sonic boom, when heard indoors, was somewhat more acceptable than it was when heard outdoors; for example, it is seen in Fig. 15 that a 2 psf boom was rated as less than acceptable by 27 percent of the people indoors, and by 42 percent of the people outdoors.

D. Subsonic Noise vs. Subsonic Noise

The KC-135 aircraft is powered by turbojet engines without noise suppressors, whereas modern-day commercial jet transports are equipped with either noise-suppressed turbojet or fanjet engines. Inasmuch as one of the purposes of the tests was to be able to relate the acceptability of sonic booms to the noise heard in communities near commercial airports, a series of tests were conducted in which the subjects judged the noise of a KC-135 to the noise from a WC-135B aircraft, the latter being equipped with fanjet engines. Some of the results are shown in Figs. 16 and 16(a). These figures illustrate the differences for the outdoor listeners as measured by various objective procedures between the noise of the WC-135B and the noise from a KC-135 when the two noises were judged to be subjectively equal.

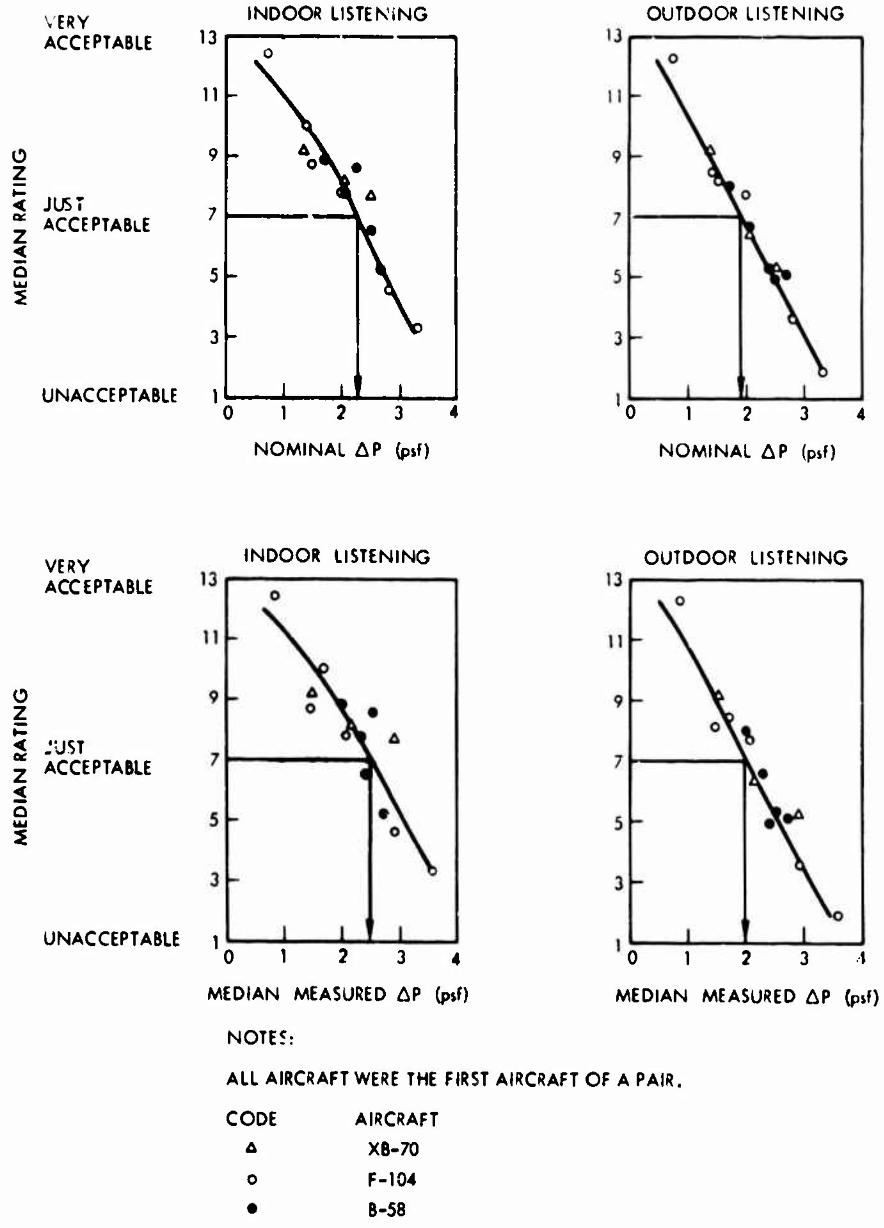
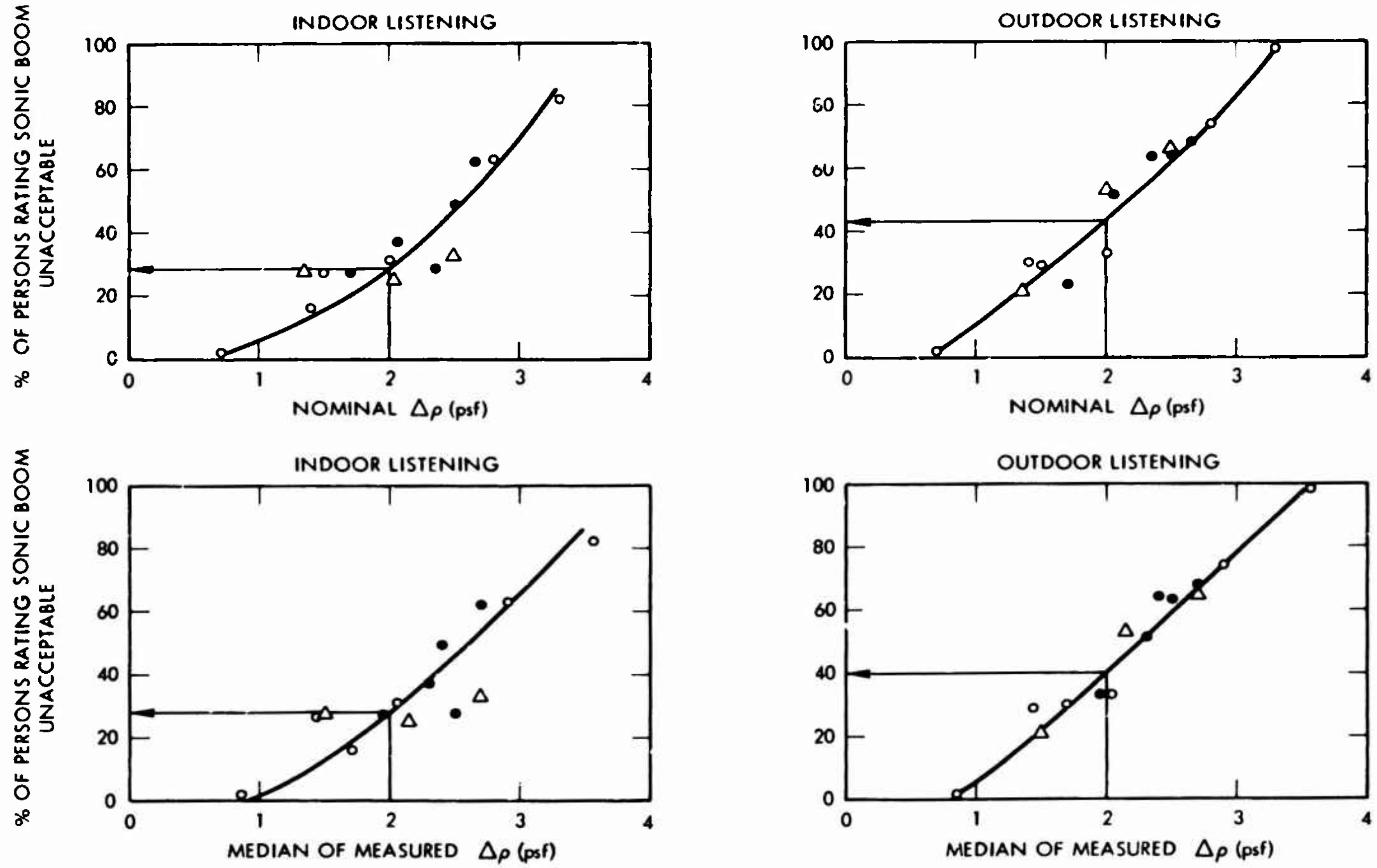


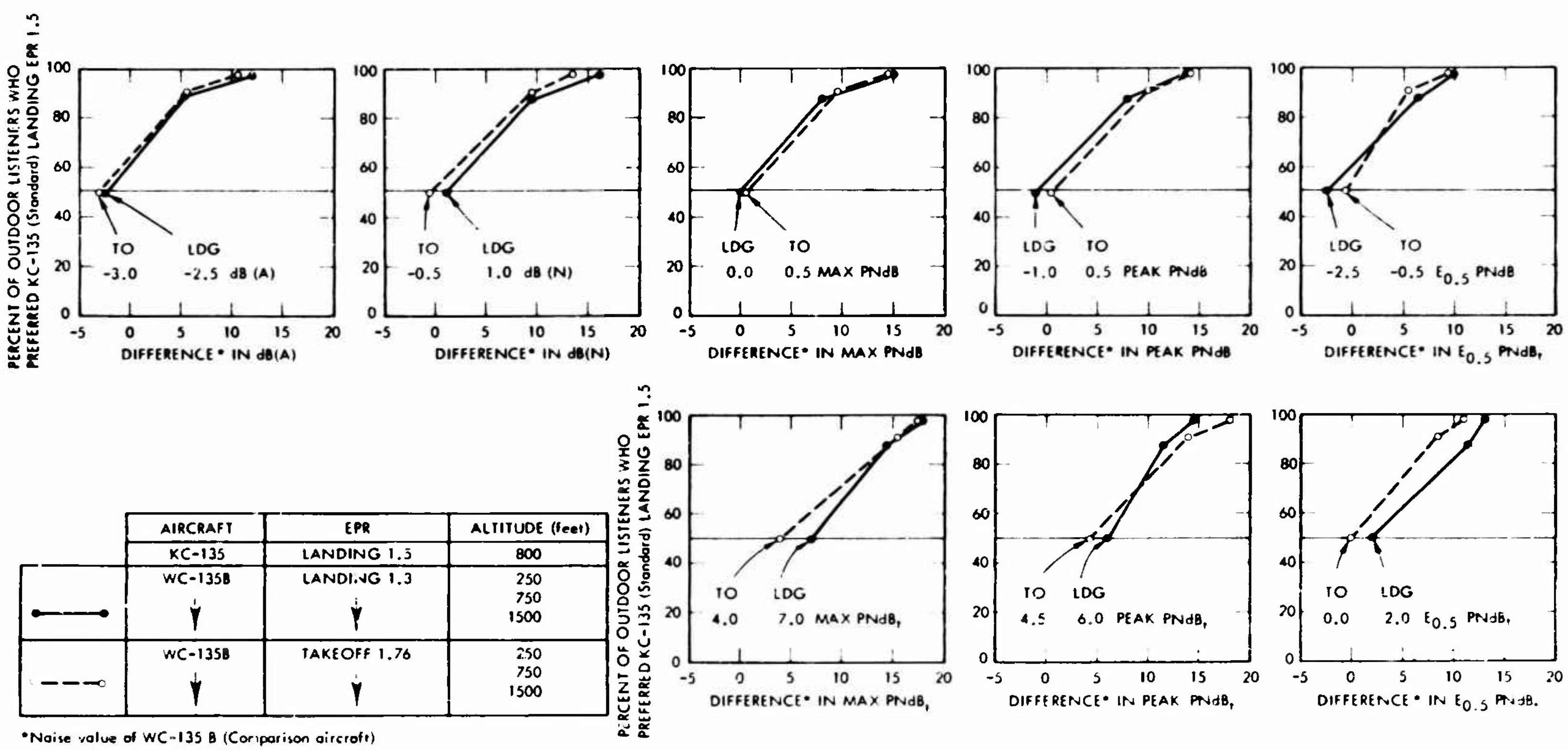
FIG. 14 MEDIAN RATINGS OF XB-70, F-104, AND B-58 SONIC BOOMS PLOTTED AGAINST NOMINAL PEAK OVERPRESSURE AND MEDIAN OF MEASURED PEAK OVERPRESSURE. Listeners from Edwards AF Base.



NOTE: All aircraft were the first aircraft of a pair.

CODE: △ XB-70
○ F-104
● B-58

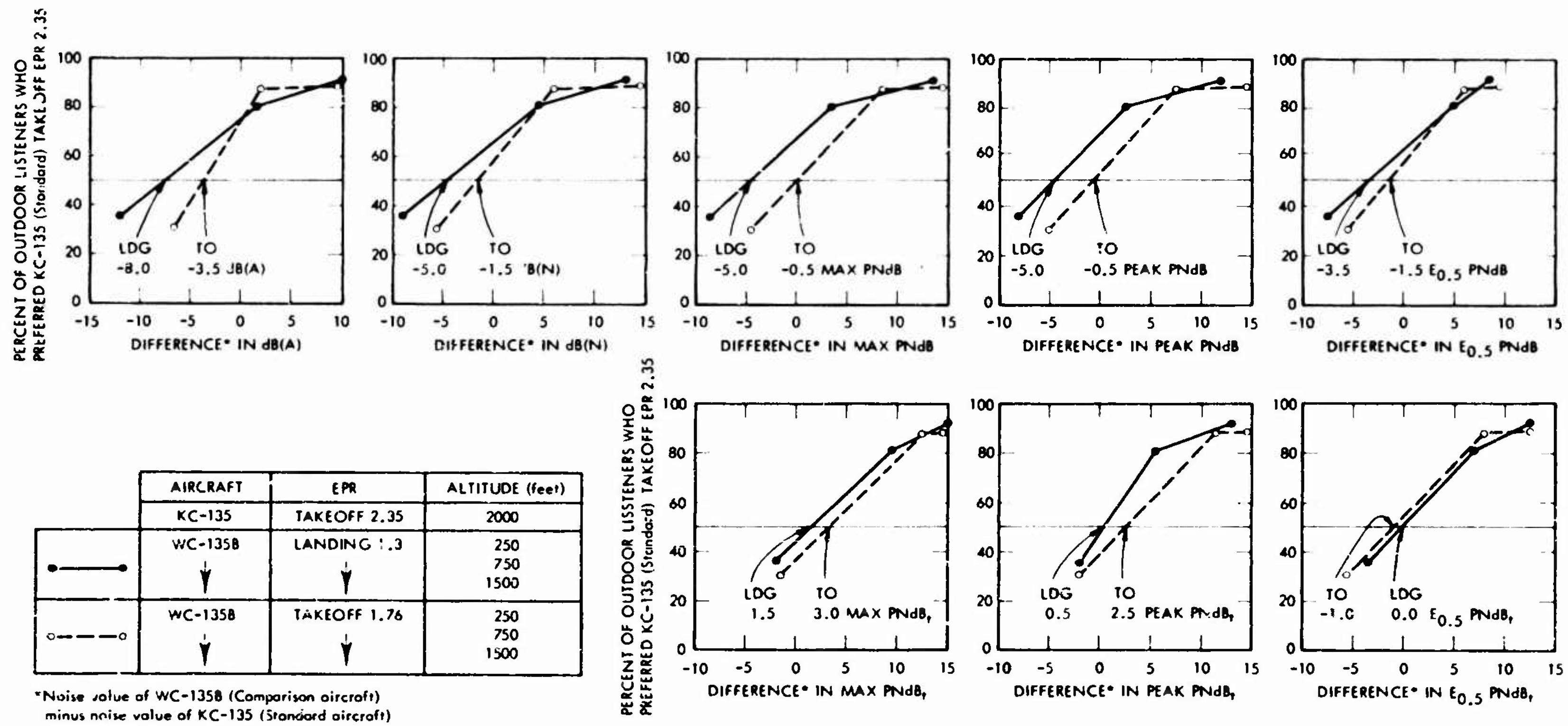
FIG. 15 PERCENT OF PEOPLE WHO RATED AS UNACCEPTABLE SONIC BOOMS FROM XB-70, F-104, AND B-58 AIRCRAFT. Listeners from Edwards AF Base.



	AIRCRAFT	EPR	ALTITUDE (feet)
	KC-135	LANDING 1.5	800
●——●	WC-135B	LANDING 1.3	250 750 1500
○- - -○	WC-135B	TAKEOFF 1.76	250 750 1500

*Noise value of WC-135 B (Comparison aircraft) minus noise value of KC-135 (Standard aircraft)
Average peak PNdB of KC-135 : 108

FIG. 16 RESULTS OF PAIRED-COMPARISON JUDGMENTS OF SUBSONIC NOISE (KC-135 landing EPR vs. WC-135B). Outdoor listeners from Edwards AF Base – Phase I.



	AIRCRAFT	EPR	ALTITUDE (feet)
	KC-135	TAKEOFF 2.35	2000
●——●	WC-135B	LANDING 1.3	250 750 1500
o– – –o	WC-135B	TAKEOFF 1.76	250 750 1500

*Noise value of WC-135B (Comparison aircraft) minus noise value of KC-135 (Standard aircraft)
Average peak PNdB of KC-135 : 111

FIG. 16 (a) RESULTS OF PAIRED-COMPARISON JUDGMENTS OF SUBSONIC NOISE (KC-135 takeoff EPR vs. WC-135B). Outdoor listeners from Edwards AF Base – Phase I.

Comparison of Various Methods of Rating Aircraft Noise. Peak perceived noise level in PNdB has been generally used in the past several years for the evaluation, from physical measurements, of the subjective noisiness of the sound from subsonic aircraft. The PNdB unit is calculated from 1/3 or full octave band spectrum levels present in the noise; these band levels are weighted and added together in a way that reflects to some extent the way in which the ear responds to the noise. It has usually been the practice to represent the perceived noisiness of sounds of equal duration by reference to highest perceived noise level attained by that sound. The highest level has been calculated in the past by two procedures: According to one procedure, the highest sound pressure level reached in each spectral band found in the physical analysis of the sound is used for the calculation of this perceived noise level. This perceived noise level is designated at Peak PNdB.

According to the second procedure, the maximum perceived noisiness of a sound is estimated by performing the calculations using the spectral band levels that occur at the 1/2 s period in time when it is found or estimated that the perceived noise level calculated for that sound will be at its maximum. This perceived noise level is designated as Max PNdB to distinguish it from Peak PNdB. When strong pure-tone components are present in a broadband noise it is usually necessary to add a "correction" factor, based on the tone-to-background noise ratio, to the PNdBs; the resulting unit is designated as Peak $PNdB_t$ of Max $PNdB_t$ as appropriate.

For stationary and most moving sources of sound, the peak or maximum perceived noise level will be found to be the same when calculated by both of these methods. However, for some moving sound sources, such as some jet aircraft (because of the geometry of the vehicle, engine size and mounting on the vehicle) different portions of the sound spectra reach their maxima at a given point in space at slightly different times; this may cause the Max PNL for some aircraft sounds to be 1-3 PNdB lower than Peak PNL calculated by the first method cited.

In order to compare the estimated total or "effective" subjective acceptability of noises of unequal durations or time patterns (a "landing

noise" of 3 s duration vs. a "takeoff noise" of 15 s duration for example) it is necessary to measure the noise in successive 1/2 s periods of time. The unit $E_d PNdB_t$ is a measure of the effective perceived noisiness of a sound taken over all of these 1/2 s intervals. The "E" designates the unit as referring to the "Effective" value of the noise occurrence, and the subscript d refers to a reference unit of time, as will be discussed below. $E_d PNdB_t$ is the sum, taken on a power basis of each $PNdB_t$ present during each 1/2 s of the noise cycle. For practical reasons a noise is said to start when it first reaches a level that is 10 dB below the maximum level reached by the noise and to stop when it declines to a level 10 dB below the maximum. The tone corrections, if required, are applied to the PNdBs calculated for each 1/2 s interval of time.

It is customary to divide the sum of these 1/2 s $PNdB_t$'s by a reference unit of time. For aircraft noise this is usually 15 s. Thus, two sounds having an equal given value of $E_{15} PNdB_t$ will be presumably judged to be equally noisy or acceptable regardless of any differences in their spectral content or durations; they should also be equal in acceptability to a reference noise that is on continuously for 15 s at a maximum $PNdB_t$ level equal to the given $E_{15} PNdB_t$ value.

It has been suggested[20] that a somewhat simpler method than that described might be suitable for evaluating the effects of durational differences among aircraft noise with respect to their perceived noisiness. In this simplified method the Max PNdB or Max $PNdB_t$ values are corrected for durational differences by adding to Max PNdB or Max $PNdB_t$ a sum proportional to 10 $\log_{10}$ of the duration in seconds between the occurrences of the levels that are 10 dB down from the maximum. The result of this calculation is called $EEPNdB_t$; the "EE" stands for "Estimated Effective." It has also been proposed as a further means of simplifying procedures for evaluating the perceived noisiness of a sound that Max PNdB be estimated from an overall measurement with a sound level meter that has an "A"- or an "N"-weighting network.[20]

Although the judgment tests conducted at Edwards AF Base were not designed to specifically examine the question of which objective method

or methods best predict the subjective judgments of the noise from subsonic aircraft, a sufficient number of such judgments were obtained to provide at least a partial evaluation of this question. Accordingly, various calculated estimates of perceived noise level for the sound for the comparison aircraft noise and for the "standard" aircraft noise were calculated, by computer, from 1/3 octave band spectra for each aircraft during each 1/2 s interval during the flyover cycle for both indoor and outdoor measurements.

In Table 10 are shown the differences in dB found for each of the objective estimates of perceived noisiness between the standard and comparison aircraft sounds when judged to be equal in noisiness by the listeners. For the indoor condition the judgment data were averaged for all the listeners in all rooms in both houses; the values calculated for the physical measures are for recordings made from the microphone located in the family room of house E-1.

It is seen in Table 10 that some of the objective measures predict the subjective results better than do others; for the better procedure the differences between the objective measures for the comparison and standard noises when judged to be equally noisy are as small as about 1 dB (ideally, of course, the differences should be 0 when the sounds are judged to be equal). The relative merit of the different objective measures to predict the subjective judgment tests is shown in Table 10 by various rank orders of merit for: (a) the average of differences, taking their sign into account, between the standard and comparison noise when judged to be equal, (b) the average deviation of the differences from the average of the differences, and (c) the average difference ignoring the sign (+ or -) of the differences). Essentially, the first statistic (a) is concerned with the central tendency of the data whereas statistics (b) and (c) reflect the general deviation or variability of the data.

Both of these factors, the average "accuracy" and the average magnitude of the variability, are important characteristics for any objective method for estimating the judged noisiness of sounds, and we have taken the liberty of treating each of these factors equally by summing and

Table 10

DIFFERENCES IN dB (COMPARISON AIRCRAFT NOIS
WHERE 50 PERCENT OF THE LISTENERS PREFER T
AND 50 PERCENT OF THE LISTENERS PREFER T

Aircraft EPR Conditions: WC-135 B (Comparison)	Aircraft EPR Conditions: KC-135 (Standard)	Average Peak PNdB of KC-135	Location of Listeners and Measuring Instruments	1* dB(A)	2 dB(B)	3 dB(C)
Landing (EPR 1.3)	Landing (EPR 1.5)	77.0	Both Indoor	1.0	-0.5	-1.0
Takeoff (EPR 1.76)	Landing	77.5	↓	1.0	2.5	4.0
Landing	Takeoff (EPR 2.35)	82.0	↓	-4.0	-8.0	-10.0
Takeoff	Takeoff	81.5	↓	-0.5	-1.5	-1.0
			Average of Differences	-0.6	-1.9	-2.0
			Rank Order	6.5	11	12
			Average Dev. from the Av. Diff.	1.6	3.1	4.0
			Rank Order	3	12	13
			Average Deviation from 0	1.6	3.1	4.0
			Rank Order	3	11	13
			Overall Rank Order	4	11.5	13
Landing	Landing	107.5	Both Outdoor	-2.5	-6.0	-7.0
Takeoff	Landing	108.5	↓	-3.0	-2.5	-0.5
Landing	Takeoff	111.5	↓	-8.0	-12.5	-13.5
Takeoff	Takeoff	110.5	↓	-3.5	-3.5	-3.0
			Average of Differences	-4.3	-6.1	-6.0
			Rank Order	11	13	12
			Average Dev. from the Av. Diff.	1.9	3.2	4.3
			Rank Order	10	12	13
			Average Deviation from 0	4.3	6.1	6.0
			Rank Order	11	13	12
			Overall Rank Order	11	13	12

* For definitions of measurements shown in columns 1 through 13 see reference 20.

† $E_{15}PNdB$ (or $E_{15}PNdB_t$) is the integration of Max PNdB (or Max $PNdB_t$) values occurring during e
adjusted to a 15 seconds standard duration.

§ EEPNdB (or $EEPNdB_t$) is Max PNdB (or Max $PNdB_t$) modified by the addition of 10 $\log_{10}$ of time,
during the flyover noise cycle.

A

Table 10

IRCRAFT NOISE MINUS STANDARD AIRCRAFT NOISE)
ERS PREFER THE WC-135B (COMPARISON AIRCRAFT)
ERS PREFER THE KC-135 (STANDARD AIRCRAFT)

2	3	4	5	6	7	8	9	10	11	12	13
B(B)	dB(C)	dB(N)	Max Phons (Stevens)	Max PNdB	Max PNdB$_t$	Peak PNdB	Peak PNdB$_t$	E_{15}PNdB†	E_{15}PNdB$_t$†	EEPNdB§	EEPNdB$_t$§
-0.5	-1.0	2.0	1.5	2.5	4.0	3.0	1.5	1.0	0.5	1.5	0.0
2.5	4.0	1.0	1.0	1.5	3.0	2.0	1.5	2.0	2.5	1.5	-2.0
-8.0	-10.0	-5.0	-4.0	-5.0	-4.0	-5.5	-5.0	-2.0	-2.0	-5.0	-8.0
-1.5	-1.0	-1.0	-0.5	-1.0	-0.5	-1.5	-1.5	-1.0	-0.5	-2.0	-4.5
-1.9 11	-2.0 12	-0.8 8	-0.5 4	-0.5 4	0.6 6.5	-0.5 4	-0.9 9	0.0 1	0.1 2	-1.0 10	-3.6 13
3.1 12	4.0 13	2.3 5	1.8 4	2.5 7.5	2.9 10	3.0 11	2.4 6	1.5 2	1.4 1	2.5 7.5	2.6 9
3.1 11	4.0 13	2.3 5	1.8 4	2.5 7.5	2.9 9	3.0 10	2.4 6	1.5 2	1.4 1	2.5 7.5	3.6 12
11.5	13	5	3	6	10	8.5	7	2	1	8.5	11.5

2	3	4	5	6	7	8	9	10	11	12	13
-6.0	-7.0	1.0	-1.0	0.0	7.0	-1.0	6.0	-2.5	2.0	-0.5	2.5
-2.5	-0.5	-0.5	-0.5	0.5	4.0	0.5	4.5	-0.5	0.0	1.0	-1.0
12.5	-13.5	-5.0	-5.5	-5.0	1.5	-5.0	0.5	-3.5	0.0	-3.5	0.0
-3.5	-3.0	-1.5	-0.5	-0.5	3.0	-0.5	2.5	-1.5	-1.0	-1.5	-0.5
-6.1 13	-6.0 12	-1.5 5.5	-1.9 7	-1.3 4	3.9 10	-1.5 5.5	3.4 9	-2.0 8	0.3 1.5	-1.1 3	0.3 1.5
3.2 12	4.3 13	1.8 7	1.8 7	1.9 10	1.6 5	1.8 7	1.9 10	1.0 2	0.9 1	1.4 4	1.2 3
6.1 13	6.0 12	2.0 7.5	1.9 6	1.5 3	3.9 10	1.8 5	3.4 9	2.0 7.5	0.8 1	1.6 4	1.0 2
13	12	7.5	7.5	4	9	5.5	10	5.5	1	3	2

ring during each 0.5 seconds between the "10 dB down" points of the flyover noise cycle,

$_{10}$ of time, measured in units of 15 seconds, between the "10 dB down" points occurring

B

averaging the rank orders achieved by each of the objective methods on these statistics. Keeping in mind the limited amount of data and limited variety of noises involved, it is to be noted that the effective tone-corrected perceived noise level (E_{15}PNdB) is consistently superior to the other methods.

We believe that the subjective data for the indoor listeners versus the indoor physical measures are not necessarily appropriate for determining small differences of merit among the physical measures because: (a) the noise environment from room to room within the houses was naturally somewhat variable due to different wall attenuation and reverberation characteristics in each room, (b) the number of subjects in any one room was too small to measure with any reliability small differences among the data, and (c) there was a certain amount of "house noise" and talking that occasionally interfered with obtaining good recordings of the aircraft noise when the aircraft noise was at weak intensities. This latter factor made calculation of EPNdB somewhat uncertain. On the other hand, the outdoor listeners were presented with a homogenous noise environment during a given flyover noise, and the recordings made outdoors of the noises in general included little or no extraneous sounds. For these reasons it is possible that the indoor physical measurements as predictors of the judgments of the indoor subjects should not be given as much weight as the data for the outdoor judgments and physical measures as a means of evaluating the efficacy of various objective calculation procedures.

Perhaps of particular interest is the fact that correcting Max PNdB by means of a durational factor proportional to 10 $\log_{10}$ of the time in seconds elapsing to the 10 dB downpoints (called Estimated Effective$_{15}$PNdB$_t$). EE_{15}PNdB$_t$ appears to be inferior to the integration method (E_{15}PNdB$_t$). This suggests that: (a) the variations in perceived noise level that occurred during a flyover cycle must be considered rather exactly in the evaluation of total perceived noisiness of a flyover sound, and (b) the assumption that the band spectral level of aircraft noise increase and decrease monotonically during the flyover cycle, as is assumed for the Estimated Effective method, is not always justified.

Attention is invited to the results for loudness levels in phons calculated according to the method proposed by Stevens. It is seen that Peak Phons predict the judgment results as well as Peak PNdB or Max PNdB. This result is to be expected, with the small sample of noise spectra involved in these tests, because of the similarity between the procedures for calculating Peak PNdB and Peak Phons (see Ref. 20).

Although $E_{15}PNdB_t$ may best predict the perceived noisiness of the sound of an aircraft flying overhead, Peak PNdB and Max PNdB have been most commonly used for this purpose. Further, it has been suggested from time to time that Peak or Max PNdB can be adequately estimated by measuring the maximum reading obtained on a sound level meter having a frequency weighting network. Weighting networks now available are the so-called A, B, and C networks, and an N-weighting network has recently been proposed.[20]

Table 11 shows, for the noise from the WC-135B aircraft at various altitudes and takeoff power, how well dB(A), (B), (C), and (N) estimate, Max PNdB and Peak PNdB. It is seen that dB(N) gives the closest estimate, a range of about 1 dB, dB(A) has a range of about 2 dB, and dB(C) a range of about 3.5 dB. It is interesting to note that the Peak PNdB values are, on the average, about 2 dB higher than Max PNdB for the same flyover sounds. This relationship has been rather consistently found for aircraft noises and is attributable to the frequency radiation pattern of the sound from the aircraft coupled with the movement of the aircraft.

E. Criterion of Significant Difference Between Boom and Noise Conditions

It is perhaps not unreasonable to suggest that a difference of 12.5 percentage points (from 50 percent to 62.5 percent) in the number of people who rate one boom to be relatively more unacceptable than another noise is of practical significance. Using this criterion it follows from Figs. 1 through 5 that on the average two noises that differ by about 3 PNdB would be significantly different when judged against a sonic boom of a nominal peak overpressure of about 1.69 psf.

Table 11

AVERAGE DIFFERENCE, AVERAGE DEVIATION OF DIFFERENCES, AND RANGE OF DIFFERENCES BETWEEN PNdB and dB(A), dB(B), dB(C), dB(N) for WC-135B AT TAKEOFF POWER AND AT VARIOUS ALTITUDES

Altitude (local altitude in feet)	Aircraft	EPR	Number of Missions	Average Max PNdB	Average Difference*				Average Deviation†				Range of Differences§			
					Max dB(A)	Max dB(B)	Max dB(C)	Max dB(N)	Max dB(A)	Max dB(B)	Max dB(C)	Max dB(N)	Max dB(A)	Max dB(B)	Max dB(C)	Max dB(N)
8000	WC-135B	Takeoff (1.76)	2	81.4	12.9	7.0	3.6	6.8	1.2	0.3	0.6	0.3	2.4	0.5	0.8	0.6
4000			7	90.6	12.1	7.4	4.1	7.2	0.6	0.3	0.4	0.4	2.4	1.1	1.6	1.3
2000			17	100.8	13.0	9.8	7.1	7.6	1.0	1.5	1.5	0.2	4.2	5.1	7.7	1.2
1300			3	105.8	13.9	9.7	6.8	7.7	0.4	1.4	1.6	0.0	1.1	3.2	3.9	0.1
1000			6	111.4	14.3	12.4	10.5	7.0	0.2	0.5	0.9	0.3	0.8	2.4	3.2	1.1
800			12	114.9	14.5	14.0	12.3	6.4	0.3	0.2	0.5	0.2	1.3	1.1	2.0	1.1
500			4	119.8	14.2	13.7	12.8	6.3	0.3	0.2	0.4	0.2	0.8	0.4	0.6	0.7
250			3	122.2	13.6	12.6	11.9	6.0	0.1	0.2	0.3	0.0	0.2	0.7	0.8	0.1
		Grand Average		105.9	13.5	11.0	8.8	7.0	0.6	0.7	0.9	0.2	2.2	2.5	3.8	1.0
				Average Peak PNdB												
8000	WC-135B	Takeoff (1.76)	2	83.0	14.5	8.6	5.2	8.4	1.7	0.8	0.1	0.8	3.4	1.5	0.2	1.6
4000			7	92.8	14.3	9.6	6.3	9.4	0.4	0.4	0.5	0.4	1.4	1.9	2.0	1.7
2000			17	102.8	15.0	11.8	9.1	9.6	1.1	1.4	1.4	0.4	4.0	5.0	6.5	2.1
1300			3	107.4	15.5	11.3	8.4	9.3	0.6	1.3	1.4	0.1	1.6	3.0	3.4	0.4
1000			6	112.9	15.8	13.9	12.0	8.5	0.3	0.3	0.8	0.5	1.0	1.4	2.1	1.9
800			12	116.4	16.0	15.5	13.8	7.9	0.3	0.2	0.5	0.3	1.2	1.3	1.8	1.3
500			4	120.8	15.2	14.7	13.8	7.3	0.4	0.2	0.2	0.3	1.0	0.5	0.7	0.7
250			3	123.0	14.4	13.4	12.7	6.8	0.3	0.4	0.1	0.2	0.6	1.1	0.3	0.6
		Grand Average		107.6	15.2	12.7	10.5	8.7	0.6	0.7	0.8	0.4	2.1	2.6	3.2	1.5

* Average Max PNdB or Average Peak PNdB minus Average Max dB(A) or [dB(B), dB(C), dB(N)].

† Average deviation of differences from the average difference.

§ Greatest difference minus least difference.

It is seen in Figs. 13 and 16 that the subjects indoors judged aircraft noise vs. aircraft noise and booms vs. booms as being significantly different, according to the criterion specified above, when they differed in intensity by about 2 PNdB and 1 dB, respectively. This increased precision in the relative judgments when the subjects judged aircraft noise vs. aircraft noise and booms vs. booms rather than aircraft noise vs. booms is to be expected from the fact that the accuracy and consistency of the relative judgments of some subjective attribute of two sounds are greater when the two sounds are similar than when they are dissimilar.[1]

Because of the nature of the paired-comparison test and the rather small number of repetitions of each test condition, probability statistics, other than those shown in Figs. 1 through 5, cannot be readily applied to the data at hand. However, in Appendix D an analysis is made of the variability present in these tests.

F. Relations Between Various Physical Measures of Sonic Booms and Ratings and Relative Judgments of Their Acceptability

The intensity of sonic booms is typically reported in terms of its peak overpressure as measured on a broadband microphone recording system having a frequency response of near 0 to 2500 Hz or so. Laboratory tests show that, other things being equal, the human listener is sensitive to rather small changes, 1 dB or so, in peak overpressure as, indeed, was found in the present tests.

However, in the present tests in and near the test houses at Edwards the listeners were a few hundred feet from the microphone and inasmuch as the peak overpressure of a boom varies to some extent from places on the ground but a few feet apart, the peak overpressures measured at the microphones could have been considerably different, on a particular boom, from the peak overpressures actually present at the ears of the listeners. Some of the variability of response to a given nominal or measured peak overpressure as shown in Figs. 12 and 13, for example, is undoubtedly due to this factor.

In an attempt to show more precisely the effects of variations in peak overpressure upon subjective ratings, six groups of subjects were placed at six locations on a line under the flight path of supersonic aircraft flown over flat desert terrain near Edwards AF Base. The aircraft were flown on a straight and level path at an altitude that would provide a nominal peak overpressure on the ground of 1.3 psf.

Figure 17 shows median acceptability ratings of F-104 booms of nominal 1.3 psf peak overpressure plotted against the peak overpressure as measured by a microphone but a few feet from each group of subjects. The results obtained on two different days are plotted separately.

It is seen in Fig. 17 that there is some relation between the actual peak overpressure and ratings even though the nominal peak overpressure was constant. It is also to be noted that there was a systematic difference between the results for the two days, the ratings on the second day being lower on the scale (less acceptable) than on the first day. We have no explanation to offer for this apparent shift in attitudes on the part of the subjects.

The rank order correlations between the ratings and the measured overpressures are given in Table 12. These coefficients of correlation bear out the conclusion that variations in peak overpressure, caused presumably by atmospheric turbulence, significantly, statistically speaking, influenced the subjective ratings of acceptability; the higher the peak overpressure, the less acceptable the boom. The fact that the relation was not even stronger could, of course, be due to some unreliability on the part of the subjects and the physical measurements as well as possible variations in other features of the boom than peak overpressure that possibly contributed to their judged acceptability.

Other Physical Measurements of Sonic Booms. The valid measurement of peak overpressure of the N wave of the sonic boom requires a microphone recording system that extends over the frequency range from about 0 to 5000 Hz or so, with most of the energy lying below 1000 Hz. There is reason to believe, however, that people (and most house structures for that matter) are not particularly sensitive or responsive to energy

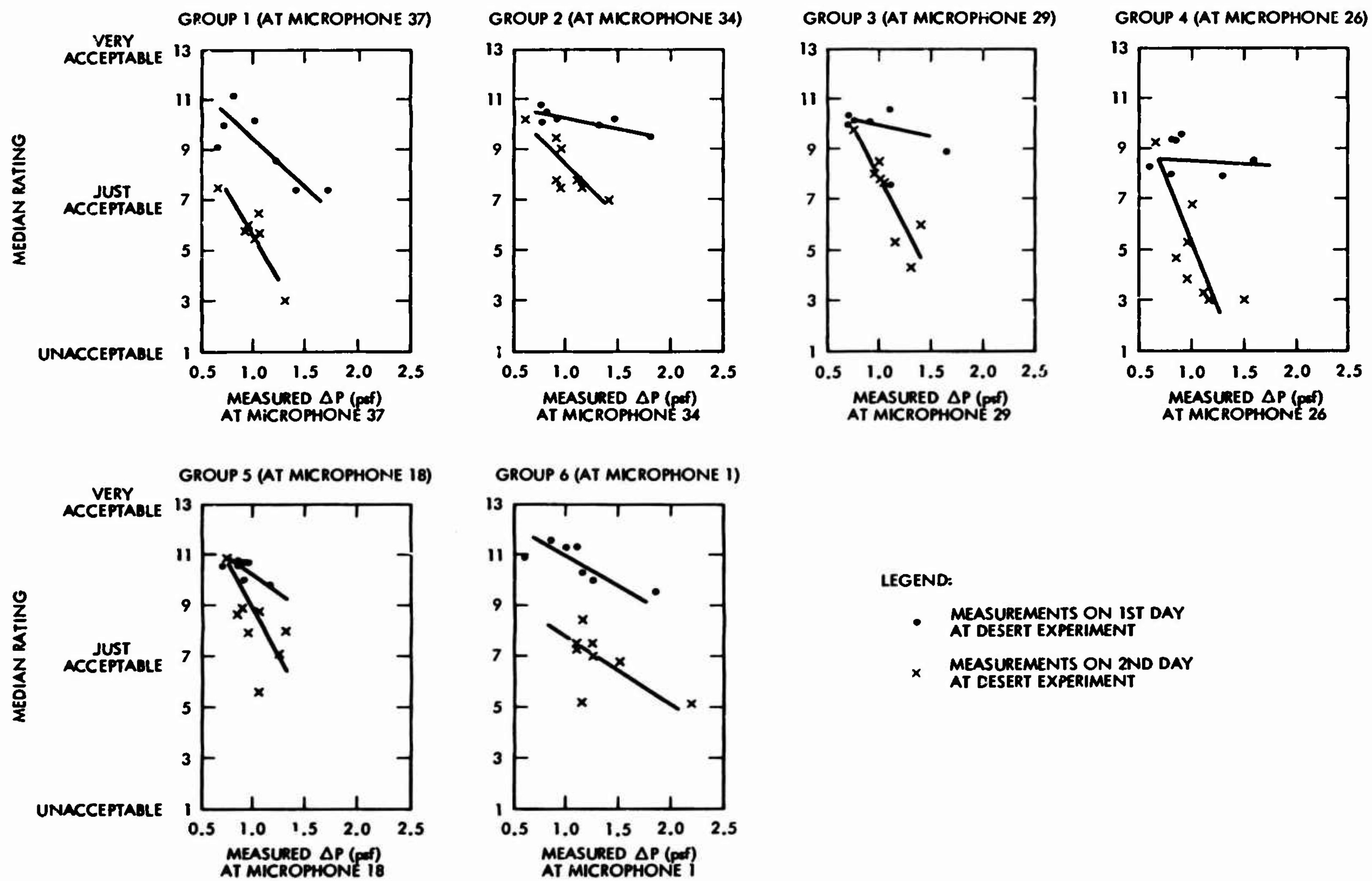


FIG. 17 MEDIAN ACCEPTABILITY RATINGS FOR SONIC BOOMS (F-104 nominal ΔP of 1.3 psf) PLOTTED AGAINST MEASURED PEAK OVERPRESSURES, DESERT EXPERIMENT

Table 12

RANK CORRELATIONS FOR DESERT EXPERIMENT
MEDIAN RATINGS OF SONIC BOOMS BY SIX GROUPS
COMPARED WITH THE PEAK OVERPRESSURE OF THE SONIC BOOMS
MEASURED AT SIX MICROPHONES DISTRIBUTED ALONG A LINEAR ARRAY
F-104 AIRCRAFT

Group	Number in Group	Located at Microphone	ΔP Measured at Microphone					
			37	34	29	26	18	1
r_1: Rank Correlation for 1st Day								
1	19	37	0.68	0.61	0.61	0.57	-0.07	-0.29
2	14	34	0.50	0.57	0.64	0.29	-0.39	0.54
3	19	29	0.00	0.39	0.39	-0.04	0.00	-0.43
4	13	26	0.36	0.61	0.68	0.07	-0.32	0.21
5	12	18	0.07	0.00	-0.29	-0.36	0.43	0.25
6	18	1	0.04	0.11	0.32	-0.43	-0.39	0.79
r_2: Rank Correlation for 2nd Day								
1	17	37	0.64	0.71	0.57	0.95	0.64	0.40
2	12	34	0.43	0.86	0.69	0.88	0.62	0.17
3	19	29	0.69	0.81	0.90	0.40	0.67	-0.31
4	12	26	0.76	0.33	0.14	0.83	0.21	0.52
5	15	18	0.10	0.24	0.48	0.31	0.69	0.29
6	14	1	0.74	0.24	0.19	0.71	0.31	0.62
r: Rank Correlation Both Days								
1	18	37	0.41	0.47	0.60	0.63	0.49	0.36
2	13	34	0.36	0.55	0.68	0.65	0.46	0.54
3	19	29	0.33	0.47	0.65	0.25	0.49	0.09
4	13	26	0.39	0.44	0.54	0.56	0.36	0.54
5	14	18	0.15	0.30	0.34	0.40	0.66	0.41
6	16	1	0.15	0.17	0.35	0.34	0.33	0.70
Distance to Microphone from Microphone 37			0	250'	500'	1100'	3100'	7100'

Date	Number of Booms Recorded at Each Microphone	Definition of Rank Correlations Shown in Above Tables	Critical Value of Rank Correlations at the 5% Level of Significance
Jan. 6, 1967	7	$r_1 = 1 - \frac{6\Sigma d^2}{7(7^2 - 1)}$	0.67
Jan. 9, 1967	8	$r_2 = 1 - \frac{6\Sigma d^2}{8(8^2 - 1)}$	0.62
Combined	15	$r = 1 - \frac{6\Sigma d^2}{15(15^2 - 1)}$	0.44
		where d is the difference in rank between the median rating and the measured peak overpressure for any one sonic boom.	

below 20 Hz or so. It is possible that measurements of only the energy in sonic boom N waves above 20 Hz or so would be as adequate a means of evaluating ghe response of people to sonic booms as is peak overpressure. To examine this question, a sample of sonic booms from the XB-70, F-104, and B-58 aircraft were analyzed by an electronic computer in terms of their energy spectra. These energy spectra were used to determine the energy in various bands as shown in Table 13.

Table 14 shows the correlations found between acceptability ratings of sonic booms and various physical measures of the booms. It is of interest to note that the correlation between the rating and the measures that exclude information regarding the energy for frequencies below 20 Hz are as high or higher than the measures, including overall peak overpressure (ΔP), which use energy below 20 Hz; compare in particular data column 4 and 5, En_{0-1000} vs. $En_{20-1000}$. Note should be made of the fact that the B-58 booms analyzed in this fashion covered such a restricted rang of overpressures that only a few significant correlations were obtained.

It can be concluded from these data that it is not necessary, even perhaps slightly misleading, to measure sonic booms in ways that include the energy in sound frequencies below about 20 Hz and above, possibly less than, 1000 Hz if one is interested in predicting only the response of people and typical house structures to the booms. If one is concerned with the effects of the atmosphere on the propagation and of the aircraft design on the generation of booms it is, of course, appropriate to evaluate the total energy and waveform of a boom from 0 to 5000 Hz or so. Also, this conclusion may not apply to other types, for example "near-field" signatures, of sonic boom pressure waveforms than those studied.

It may at first seem somewhat surprising that a major portion of the energy in the boom--that below 20 Hz--and the frequencies to which the ear is most sensitive--those above 1000 Hz--can be discarded for these boom measurement and evaluation purposes. As aforementioned, people and typical structures do not respond very much to the very low frequencies, and the energy in the frequencies above 1000 Hz is relatively very small in a sonic boom.

Table 13

AVERAGE VALUE AND AVERAGE DEVIATION FROM AVERAGE VALUE FOR MEASUREMENTS OF SONIC BOOMS RECORDED OUTDOORS

Aircraft	Nominal ΔP		Number of Missions		Measurement							
	dB*	psf			ΔP dB*	En 0-50 dB*	En 0-200 dB*	En 0-1000 dB*	En 20-1000 dB*	En 20-200 dB*	En 10-30 dB*	En Total dB*
XB-70	135.61	2.52	4	Avg.	136.00	123.93	124.00	124.01	111.70	111.50	113.14	124.01
				Avg. Dev.	0.37	1.16	1.14	1.15	0.19	0.17	0.58	1.15
XB-70	133.86	2.06	6	Avg.	134.22	123.23	123.27	123.28	108.73	108.53	111.47	123.28
				Avg. Dev.	1.08	0.43	0.43	0.43	0.60	0.57	0.54	0.43
XB-70	130.25	1.36	3	Avg.	130.21	117.51	117.62	117.63	104.56	104.38	107.17	117.63
				Avg. Dev.	0.42	0.38	0.31	0.31	1.32	1.26	0.82	0.31
F-104	136.52	2.80	7	Avg.	137.79	120.74	121.13	121.19	116.35	116.18	117.84	121.19
				Avg. Dev.	1.21	1.10	1.07	1.05	1.12	1.19	1.13	1.05
F-104	132.14	1.69	2	Avg.	134.83	116.98	117.47	117.53	110.98	110.83	114.08	117.53
				Avg. Dev.	1.51	0.20	0.53	0.58	2.50	2.54	0.46	0.58
F-104	130.50	1.40	10	Avg.	130.54	115.03	115.22	115.25	107.17	107.00	110.97	115.25
				Avg. Dev.	1.45	1.10	1.09	1.09	1.74	1.74	1.38	1.09
F-104	125.08	0.75	11	Avg.	126.81	111.70	111.81	111.84	101.78	101.65	104.81	111.84
				Avg. Dev.	2.08	1.59	1.59	1.60	2.50	2.46	1.99	1.60
B-58	135.61	2.52	4	Avg.	135.60	122.42	122.49	122.50	110.90	110.70	113.33	122.50
				Avg. Dev.	0.39	0.94	0.92	0.92	0.82	0.75	0.59	0.92
B-58	134.93	2.33	16	Avg.	136.04	121.71	121.81	121.82	110.70	110.51	113.43	121.83
				Avg. Dev.	1.25	0.42	0.43	0.42	1.55	1.50	0.98	0.45
B-58	133.86	2.06	5	Avg.	134.34	121.14	121.24	121.25	109.60	109.39	112.38	121.25
				Avg. Dev.	0.68	0.43	0.43	0.42	0.98	1.03	0.74	0.42
B-58	132.14	1.69	17	Avg.	132.40	119.49	119.56	119.57	106.52	106.36	109.85	119.57
				Avg. Dev.	1.18	0.89	0.91	0.91	1.79	1.75	1.28	0.91
		Total	85									
Grand Avg.	132.40				133.13	119.06	119.19	119.21	108.40	108.23	111.25	119.21
Grand Avg. Dev.					1.23	0.86	0.86	0.86	1.52	1.50	1.13	0.87

* These measures are calculated using pressures expressed in units of 0.0002 dyne/cm^2. The subscripts of En (energy measures) indicate the limits of energy bands. For example $En_{20-1000}$ designates an energy measurement in the band 20 Hz to 1000 Hz and is defined as the integral of the energy spectral density function between the limits 20 Hz to 1000 Hz.

Table 14

RANK CORRELATIONS BETWEEN MEDIAN RATINGS AND VARIOUS ENERGY MEASUREMENTS OF SONIC BOOMS RECORDED OUTDOORS

Subjects	Aircraft	Nominal ΔP (psf)	Number of Missions, N	Critical Value at 5% Level of Significance	Measure							
					ΔP	En_{0-50}	En_{0-200}	En_{0-1000}	$En_{20-1000}$	En_{20-200}	En_{10-30}	En_{Total}
Edwards Indoor	XB-70	2.52, 2.06, and 1.36	5	0.81	0.90*	0.30	0.30	0.30	0.90*	1.00*	0.90*	0.30
	F-104	2.80, 1.40, and 0.75	18	0.40	0.93*	0.92*	0.92*	0.92*	0.94*	0.94*	0.92*	0.92*
	B-58	2.52, 2.33, and 2.06	12	0.50	0.32	0.31	0.31	0.44	0.53*	0.51*	0.27	0.44
Edwards Outdoor	XB-70	2.52, 2.06, and 1.36	5	0.81	0.80	0.60	0.60	0.60	1.00*	0.90*	1.00*	0.60
	F-104	2.80, 1.40, and 0.75	18	0.40	0.89*	0.88*	0.87*	0.87*	0.90*	0.90*	0.88*	0.89*
	B-58	2.52, 2.33, and 2.06	12	0.50	0.32	0.42	0.42	0.39	0.17	0.17	0.14	0.39

* Rank Correlation greater than Critical Value.

Notes:
1. All judgments were made on the 1st sound of a pair of aircraft sounds.
2. The rank order correlation is defined as $1 - [6 \Sigma d^2/N(N^2 - 1)]$ and d is the difference in ranks (in this case, the difference in the ranks of the median ratings and the ranks of the physical measurements). The critical value at the 5% level of significance varies with the value of N.
3. The subscripts of En (energy measures) indicate the limits of energy bands, e.g. $En_{20-1000}$ designates an energy measurement in the band 20 Hz to 1000 Hz and is defined as the integral of the energy spectral density function between the limits 20 Hz to 1000 Hz.

With regard to the latter point the correlations obtained also seem reasonable because:

(a) the rise time of the booms from these aircraft were such that their spectra fell off at the same rate, about 12 dB per octave, at frequencies above about 500 Hz

(b) the frequencies in the booms that contribute the most to perceived noisiness or loudness (i.e., exceed the threshold of hearing by the greatest amount) are in the region of 200 Hz.

Comparison of Perceived Noise Levels of Sonic Booms and Aircraft Noise. Because of the great difference between the duration and spectra of sonic booms and the flyover noise from subsonic aircraft it would be surprising if physical energy measures of these two events would correspond in magnitude when they were judged or rated as subjectively equal by listeners. Nevertheless, 1/3 octave band spectra were found for XB-70 sonic booms recorded indoors and nominal outdoor XB-70 sonic booms. PNdBs were calculated for each of these spectra (see Tables 15 and 16). The PNdBs for the booms are designated as Effective PNdB for a 0.5 s interval ($E_{0.5}$PNdB) inasmuch as the booms did not exceed 0.5 s (0.5 s is a unit of time that has been suggested as appropriate for measuring sound with respect to its effect on people).[20] Because of their short duration, less than 0.5 s, by definition $E_{0.5}$PNdB and Peak PNdB have the same value for sonic booms. In Fig. 18 acceptability ratings are plotted against $E_{0.5}$PNdB (Peak PNdB) for sonic booms and Peak PNdB and $E_{0.5}$PNdB for subsonic aircraft noise. It is worthy of note in Fig. 18 that there is a reasonably good correlation for outdoor physical measurements vs. outdoor judgments between PNdB and rating for either subsonic aircraft noise or sonic booms. For the indoor data the relation between the subjective and physical measures is not as close for the sonic booms as it is for the aircraft noise. This should perhaps be expected because of greater variability in the reactions of individual rooms in the test houses to sonic booms than to the aircraft noise. However, it is clear that booms of a given $E_{0.5}$PNdB (or Peak PNdB) did not receive, within 14-16 dB, the same acceptability rating as did the noise from a subsonic aircraft having the

Table 15

OUTDOOR ΔP AND $E_{0.5}$ PNdB AND 1/3 OCTAVE BAND ENERGY SPECTRA AND $E_{0.5}$ PNdB MEASURED IN THREE ROOMS INDOORS--XB-70 SONIC BOOM

Location	Mission	Δp Average of 5 Outdoor Measurements psf	Δp Average of 5 Outdoor Measurements dB*	$E_{0.5}$ PNdB Outdoor Nominal†	Sound Energy Level, dB--Recorded Indoors, Center Frequencies 50	63	80	100	125	160	200	250	315	400	500	630	800	1000	$E_{0.5}$ PNdB§ Indoor Measurement
1B (House E1, Bedroom)	1-1	2.91	136.86	101	78	74	79	82	77	70	63	60	60	60	54	52	53	54	82
1K (House E1, Kitchen)					73	78	78	73	72	63	63	61	58	57	57	54	54	54	77
2D (House E2, Dining Room)					84	78	75	77	77	71	70	68	61	60	57	57	57	55	82
																			Avg. 80
1B	2-1	2.55	135.71	100	70	60	70	69	63	63	56	55	52	53	49	53	52	47	70
1K					70	69	75	75	71	63	59	60	57	55	55	55	55	52	76
2D					86	76	78	85	76	74	74	69	65	59	59	59	60	56	86
																			Avg. 77
1B	10-1	2.41	135.22	100	73	72	80	65	68	65	62	63	61	55	55	56	54	55	78
1K					71	70	72	74	72	63	60	66	65	57	63	67	70	72	82
2D					76	71	72	73	70	69	69	66	56	57	55	52	52	52	77
																			Avg. 79
1B	15-1	2.18	134.35	99	75	74	78	72	68	70	70	61	62	59	54	53	53	52	78
1K					71	70	67	70	67	64	63	59	58	56	56	53	53	53	73
2D					74	75	73	72	70	70	69	64	61	58	55	54	54	53	77
																			Avg. 76
1B	14-1	2.10	134.02	99	69	69	77	68	63	63	65	60	57	56	53	51	50	50	75
1K					71	68	65	63	61	59	57	55	54	52	51	51	50	49	67
2D					80	71	72	71	68	72	70	64	62	61	57	56	54	52	78
																			Avg. 73
1B	9-1	2.09	133.98	99	59	64	67	62	61	59	54	50	49	50	48	46	44	42	65
1K					73	69	74	73	71	63	61	58	59	57	53	53	53	51	75
2D					76	72	73	68	70	69	67	62	61	59	55	53	52	51	75
																			Avg. 72
1B	6-2	1.78	132.59	97	73	69	72	71	75	74	75	60	58	55	53	50	50	48	80
1K					77	74	72	72	64	65	63	59	59	56	55	51	51	50	74
2D					85	74	69	75	71	69	66	61	61	57	54	53	52	52	80
																			Avg. 78
1B	5-2	1.19	129.09	94	68	66	66	65	69	68	59	56	53	52	50	49	49	48	72
1K					72	66	61	66	57	59	58	56	52	52	50	50	50	49	68
2D					77	69	63	70	67	63	65	60	60	58	56	54	53	54	74
																			Avg. 71

* re 0.0002 μbar.

† PNdB calculated from nominal spectrum of boom from XB-70 with rise time of 0.005 seconds and the iven peak over-pressures.

§ PNdB calculated from measured spectra.

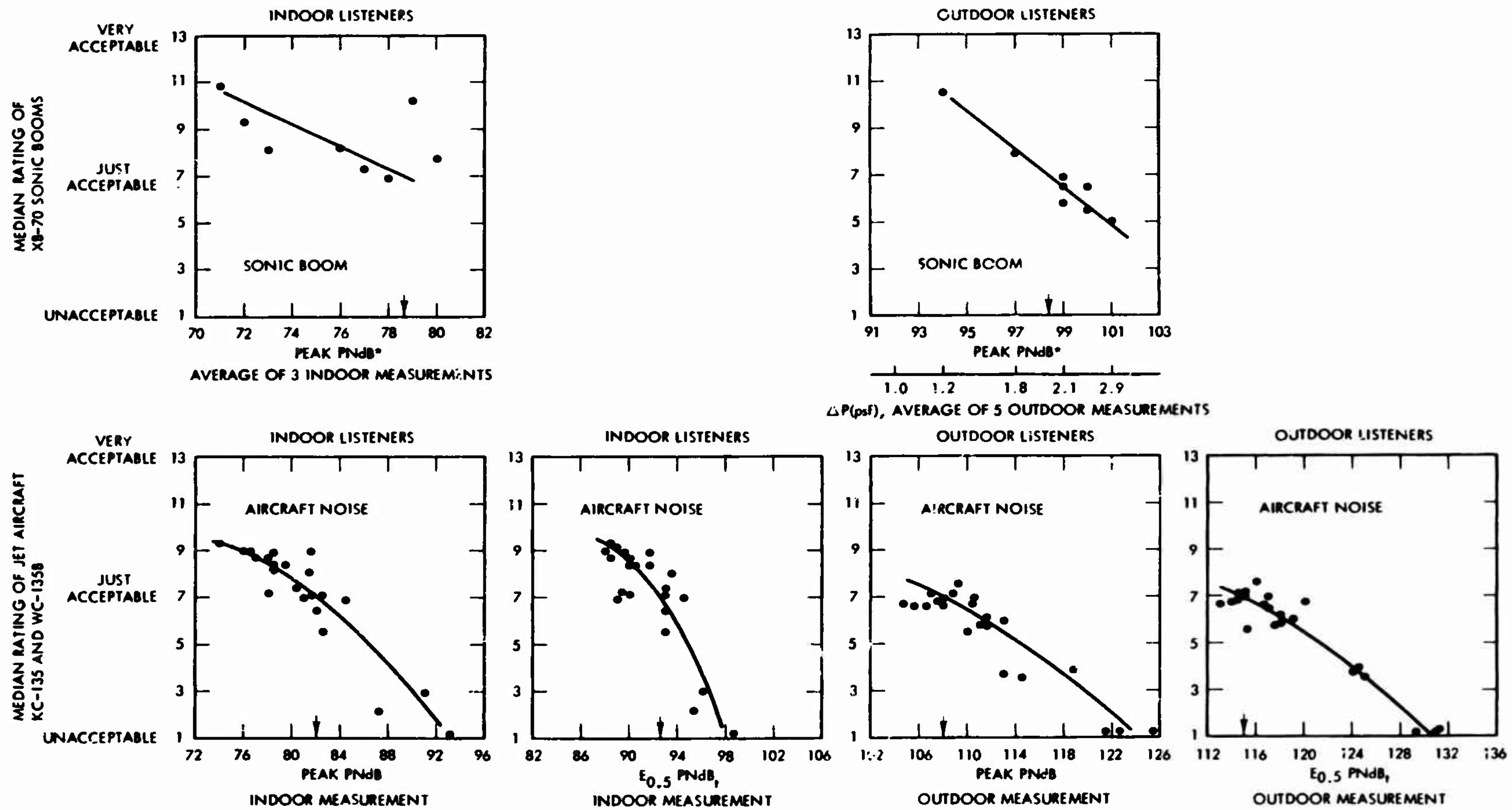
Table 16

NOMINAL OUTDOOR 1/3 OCTAVE BAND ENERGY SPECTRA AND $E_{0.5}$PNdB - XB-70 SONIC BOOM

Mission	ΔP		Sound Energy Level, dB--Nominal Outdoors																		$E_{0.5}$PNdB †
			Center Frequencies																		
	psf	dB*	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	
1-1	2.91	136.86	102	102	99	96	93	87	73	81	81	71	75	68	67	64	60	58	54	52	101
2-1	2.55	135.71	101	100	98	95	92	86	72	80	80	70	73	67	66	63	59	57	53	51	100
10-1	2.41	135.22	101	100	98	95	92	86	72	80	80	69	73	67	65	62	59	57	53	50	100
15-1	2.18	134.35	100	99	97	94	91	85	71	79	79	69	72	66	64	61	58	56	52	50	99
14-1	2.10	134.02	100	99	96	94	90	85	71	79	79	68	72	66	64	61	58	55	51	49	99
9-1	2.09	133.98	100	99	96	94	90	85	71	79	79	68	72	66	64	61	58	55	51	49	99
6-2	1.78	132.59	98	97	95	92	89	83	69	77	77	67	70	64	62	60	56	54	50	48	97
5-2	1.19	129.09	95	94	92	89	85	80	66	74	74	63	67	61	59	56	53	50	47	44	94

* re 0.0002 μbar

† PNdB calculated from nominal spectra of boom from XB-70 with rise time of 0.005 seconds.



*Peak PNdB for the sonic boom is equal to $E_{0.5}$ PNdB, because the duration of the booms was less than 0.5 seconds and there were no tone corrections required. The peak for the outdoor booms are calculated from nominal spectrum of boom from XB-70 with rise time of 0.005 seconds and the given peak overpressures.

FIG. 18 COMPARING PEAK PNdB AND $E_{0.5}$ $PNdB_T$ FOR XB-70 SONIC BOOMS AND FOR NOISE FROM SUBSONIC AIRCRAFT WHEN BOTH ARE JUDGED TO BE EQUALLY ACCEPTABLE ON RATING SCALE.

same $E_{0.5}$PNdB. The Peak PNdB values of the boom and aircraft noise agreed within 2 PNdB (outdoors) to about 8 PNdB (indoors) when the boom and noise received equal ratings; however, in our opinion, these relations are probably fortuitous and would not be found with noises having different durations than the aircraft noise present for these tests. Further knowledge of the relations between the physical aspects of sound and subjective reactions to it must be obtained before one can closely equate PNdBs for noises as different as sonic booms and subsonic aircraft noise, although it seems clear that in comparing or ranking the subjective acceptability of one sonic boom relative to another boom, $E_{0.5}$PNdB (or Peak PNdB) can be expected to do as well as, or better than other physical measures (compare Fig. 18 vs. Figs. 14 and 17).

G. Differences in Responses of Subjects in Different Test Rooms and on Vibration Isolation Pads

Comparisons between the average subjective ratings made by listeners outdoors, in different houses, and in different rooms of the one-story and two-story "midwest" test houses, can be made by reference to Table 5. In Table 5 the percentage is given of the people in the respective groups who rated the booms and the noise from subsonic aircraft as being unacceptable (less than "just acceptable").

Figures 19 and 20 show histogram distributions of ratings assigned by subjects in the various test locations for B-58 booms having a nominal overpressure of 1.69 psf and 2.65 psf, respectively.

Table 5 shows that there were no clear-cut differences among the averages for the Edwards AF Base house built of cement block, the two special frame houses, and for the listener group located out of doors. However, it would appear from Table 5 that either the subjects or the acoustic-vibration stimulation differed significantly among some of the individual rooms in houses "E-1" (the one-story frame house) and "E-2" (the two-story frame house). It is possible, of course, that the subgroups, by room, of the subjects differed significantly in their sensitivity to noise and sonic booms. In view of the relative unimportance of this possibility to the overall results and of their need for the most

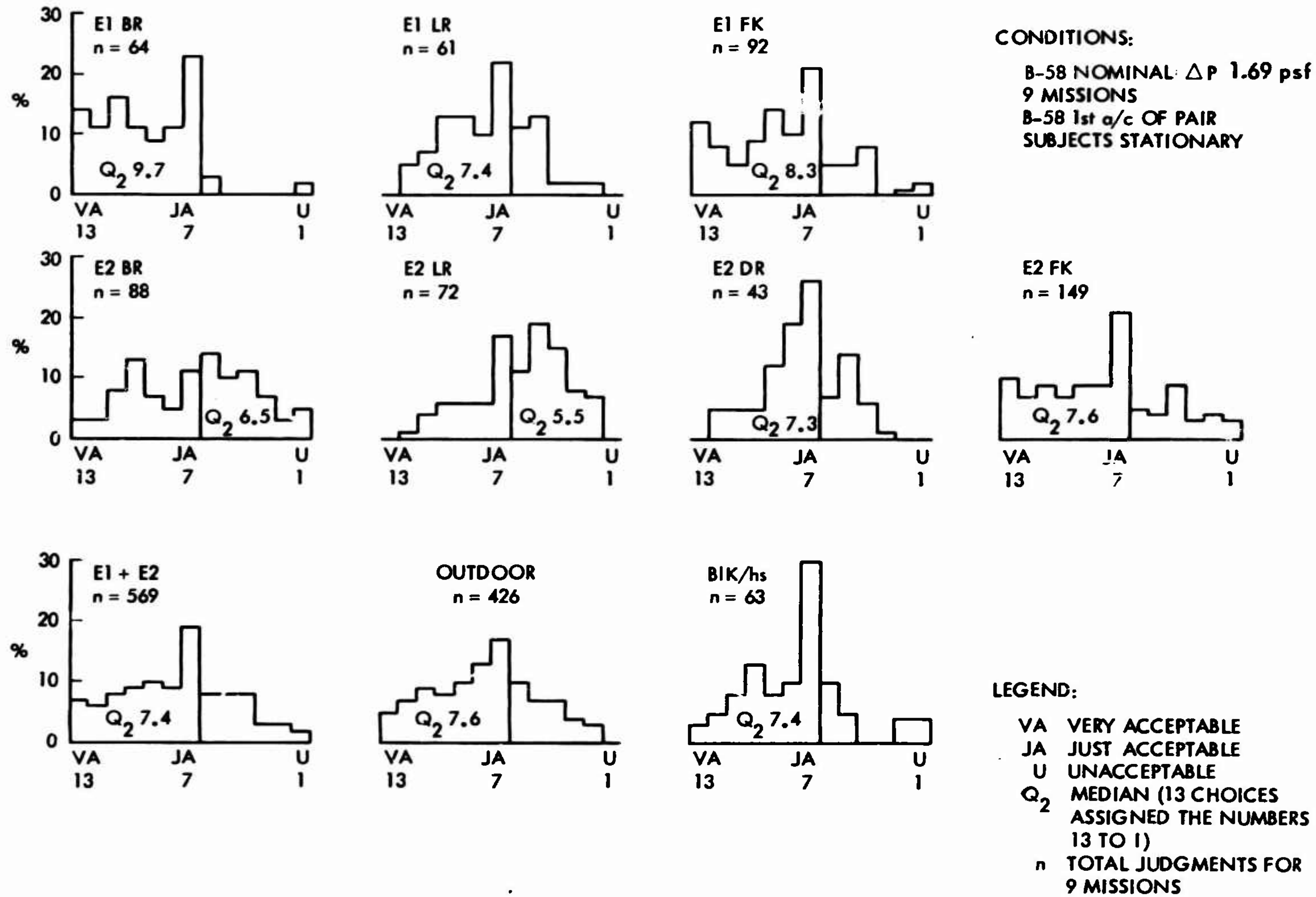


FIG. 19 DISTRIBUTION OF ACCEPTABILITY RATINGS BY LOCATION (B-58 nominal ΔP 1.69 psf). Listeners from Edwards AF Base – Phase I.

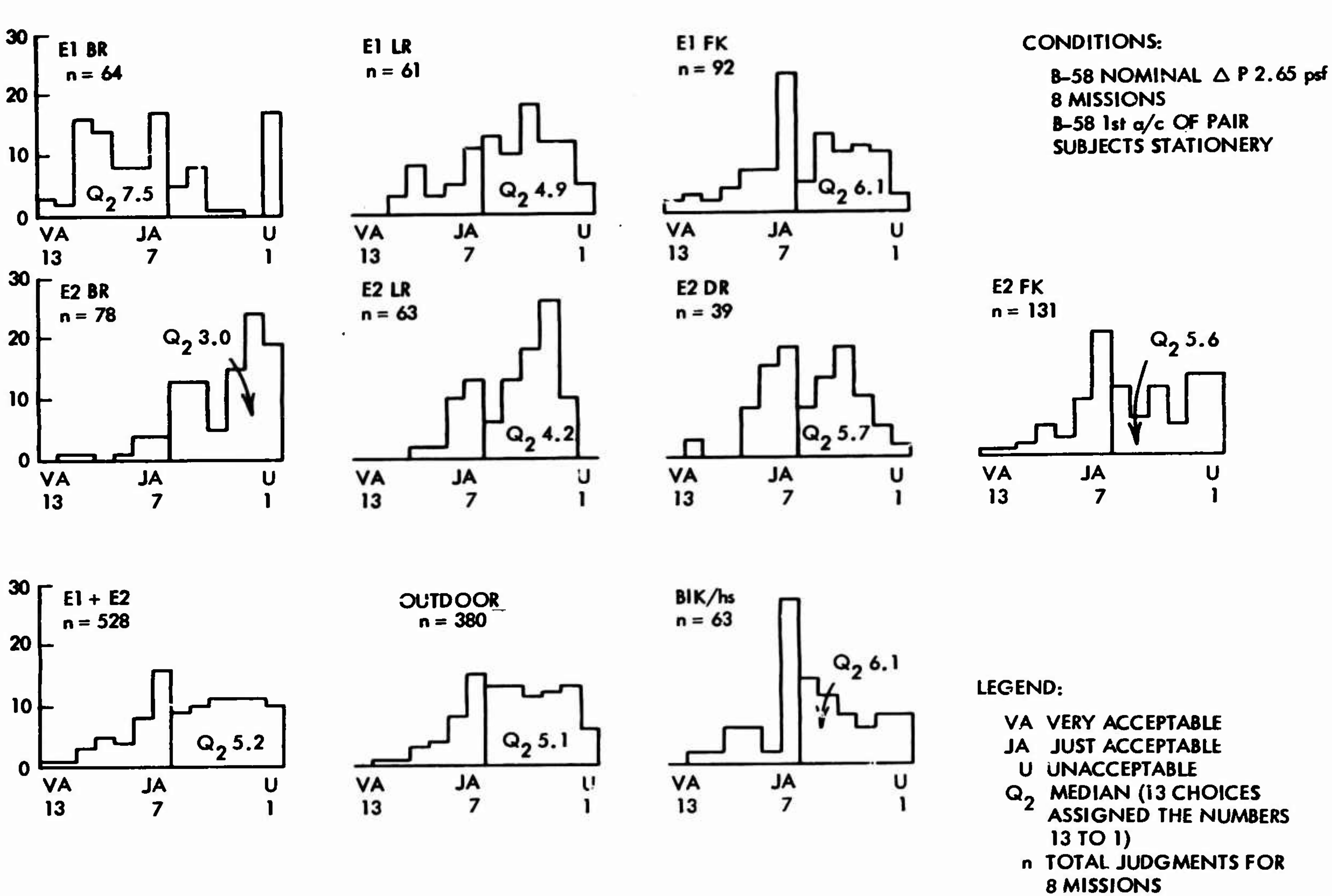


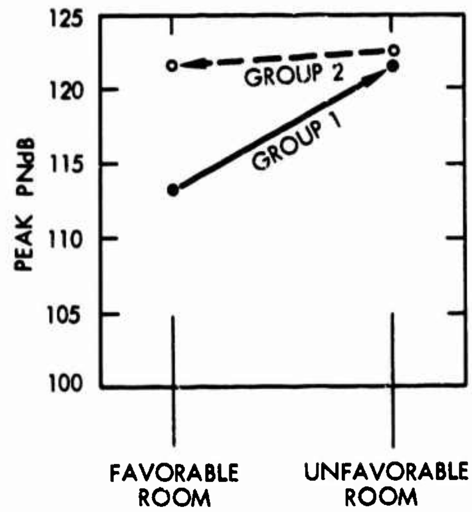
FIG. 20 DISTRIBUTION OF ACCEPTABILITY RATINGS BY LOCATION (B-58 nominal ΔP 2.65 psf).
Listeners from Edwards AF Base – Phase I.

efficient use of the aircraft and test facilities to meet the objective of the experiments, it was not deemed advisable to "rotate" systematically all the subjects among the various test rooms to find out if the subgroups of subjects would respond similarly when in exactly similar noise-vibration environments.

Examination of the data in Table 5 reveals that the subjects in some rooms rated the boom and the noise from the subsonic aircraft as being less acceptable than did the subjects in other rooms. Some rooms that achieved, on the average, the worst ratings for booms were not necessarily the rooms in which the subjects gave the worst ratings to the noise from subsonic aircraft. Although the subjects were randomly assigned to the chair locations at the beginning of the tests, they kept, except for certain special tests, the same position throughout the tests. Accordingly, it is possible that some of the difference between ratings among the different groups of subjects by their location could be due to inherent differences in the sensitivity of the two groups to sounds.

As a check on this possibility, subjects from one of the rooms that on the average gave the least acceptable ratings and subjects from one of the rooms that gave the most acceptable ratings exchanged their locations for a series of 16 missions. The results given in Fig. 21 indicate that at least some of the differences among the ratings given in the test rooms were indeed due to room and not subject differences.

<u>Relation Between Ratings of Sonic Booms and Wall Displacements in Individual Test Rooms</u>. Measurements made by accelerometers and displacement gauges located at various points throughout the test houses indicated that the displacement of the external walls of the test rooms (so-called plate response) appear to be the largest and most sensitive measures of the effects of various sonic booms on the houses. On the bottom row of the graphs in Fig. 22 are plotted the average displacement in inches for a wall of three of the test rooms as a function of the peak overpressure, measured outdoors, of the sonic booms made by F-104, B-58, and XB-70 aircraft. It is seen for these measures that the magnitude of the wall displacement is approximately equal for the booms of equal overpressure from XB-70 and B-58 aircraft whereas there is apparently less



GROUP	NORMAL LOCATION	FAVORABLE ROOM	UNFAVORABLE ROOM	NET CHANGE
1	FAVORABLE ROOM	113.5 PNdB	121.5 PNdB	8 PNdB
2	UNFAVORABLE ROOM	121.5 PNdB	122.5 PNdB	1 PNdB
Average		117.5 PNdB	122 PNdB	4.5 PNdB

FIG. 21 RESULTS OF PAIRED-COMPARISON JUDGMENTS SHOWING HOW JUDGMENTS CHANGED FOR THE SAME SUBJECTS WHEN MOVED TO DIFFERENT ROOMS
Data are Peak PNdB levels of subsonic aircraft noise judged to be as acceptable as B-58 boom of 2.33 psf nominal peak overpressure. Listeners from Edwards AF Base.

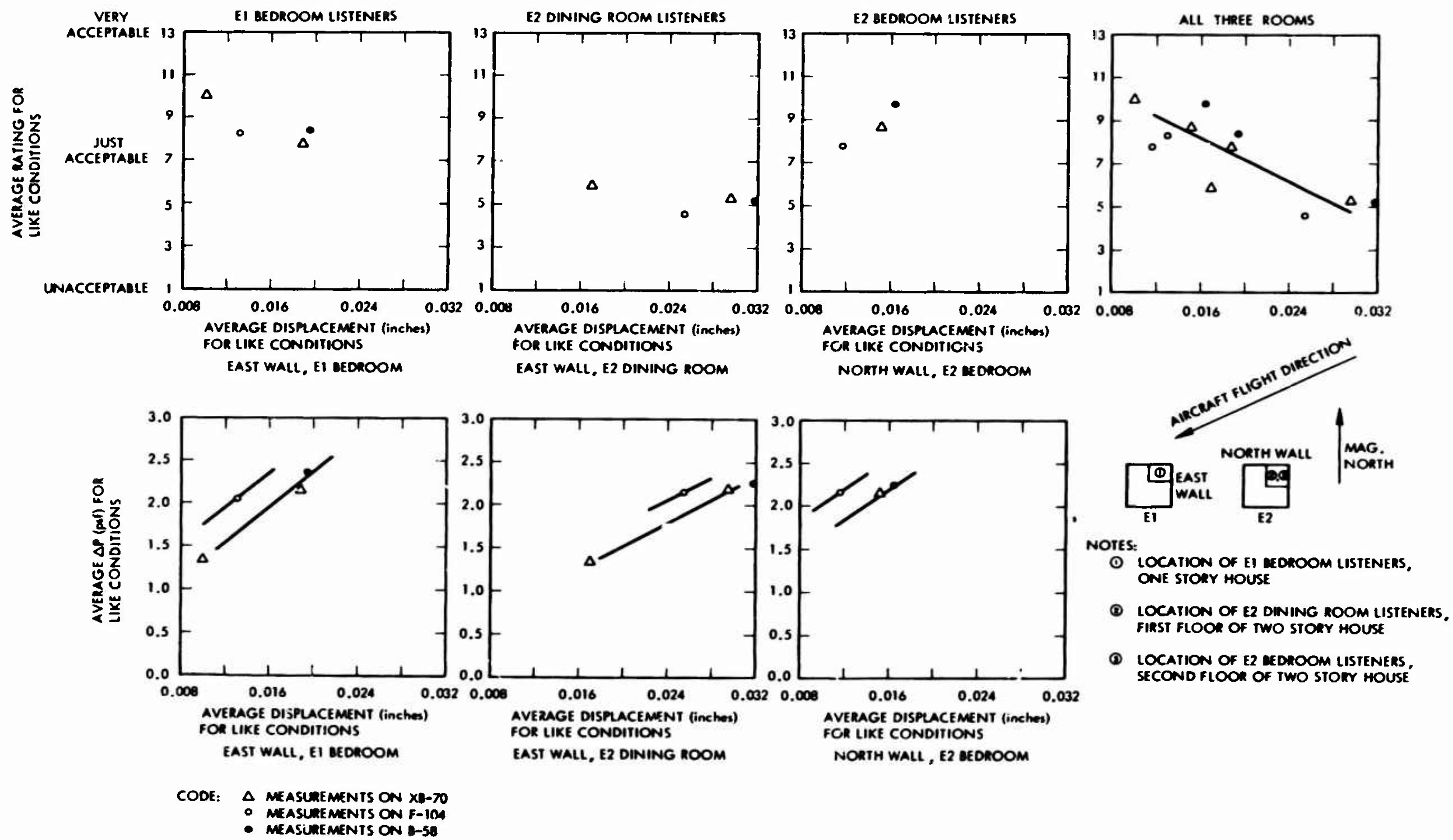


FIG. 22 SHOWING RELATIONS BETWEEN ACCEPTABILITY RATINGS AND ROOM WALL DISPLACEMENTS (upper row) AND AVERAGE PEAK OVER PRESSURES AND ROOM WALL DISPLACEMENTS (lower row) TO SONIC BOOMS FROM XB-70, F-104, AND B-58 AIRCRAFT

displacement of the walls from the boom of the F-104 aircraft, but of comparable peak overpressure. As discussed elsewhere, this result is not expected inasmuch as the boom of the B-58 and XB-70 aircraft contain more energy than the boom from the F-104 at frequencies of around 10-20 Hz, frequencies which apparently were particularly effective in moving the walls of the rooms. Apparently, also, is the fact that the location and precise construction of the individual test rooms in the houses influenced the magnitude of the displacement of the individual walls of the room. It is beyond the scope of the present paper to attempt to relate the interactions between house structure, sonic booms, and response of individual walls and other components within the test houses.

Shown in the top row of graphs on Fig. 22 are the average ratings given to the sonic booms that caused the wall displacements shown in the graphs in the bottom row of the figure. On the upper right-hand graph in Fig. 22 are plotted the ratings obtained as a function of wall displacement independently of the test rooms in which the listeners were located. This is done on the presumption that while individual rooms obviously respond differently to the sonic booms the listeners themselves tend to respond to the magnitude of the acoustic and vibrational (either direct or indirect) stimuli reaching them as a result of the sonic boom imposed upon the house structures. Although the data are perhaps too variable, due to both errors of measurement and the presence of other acoustic factors than those related exactly to the wall displacements as measured, there is present a reasonable trend between magnitude of wall displacement and the acceptability ratings received for the individual sonic booms; the greater the displacement, in general, the more unacceptable being the rating being received by a sonic boom.

It might be deduced also that whereas the sonic boom from the F-104 caused somewhat less wall displacement than did the booms from the other aircraft, there were other aspects of the boom from the F-10_ that contributed to its unacceptability ratings which, for a given wall displacement appeard to be about equal to or greater than the ratings received

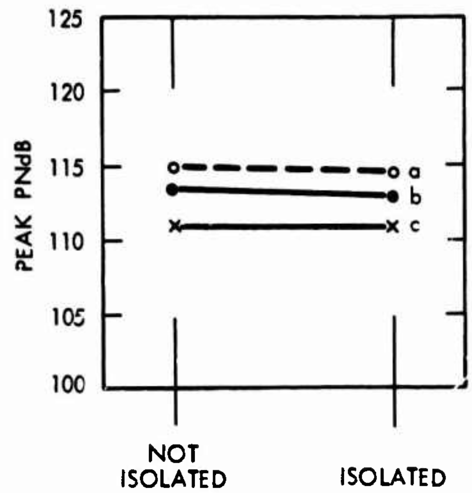
by the other booms. It is possible that the boom from the F-104 had a slightly shorter rise time and a sharper "crack" to it than the booms from the other aircraft because the boom path to the ground from the F-104 was shorter than for the other aircraft and the boom had less opportunity to be disturbed and distorted by atmospheric effects (the F-104 had to fly at a considerably lower altitude than the B-58 or XB-70 in order to generate on the ground a boom of comparable peak overpressure). Both the psychological and physical measurements made were not precise enough to demonstrate with any certainty some of these possible detailed effects and relations.

The relation between the judgment ratings and wall displacements found within the individual test rooms, while interesting, is perhaps of somewhat academic importance. It is to be expected in real life that not only will people and given rooms in houses differ in their responses to sonic booms and noise from subsonic aircraft, but also that the interaction between these sounds and given rooms or structures will differ, depending on the angle of incidence of the sounds with the structure. From a practical point of view, it is the ratings taken over all types of houses, listening conditions, and directions of aircraft flight tracks that are important in evaluating the reaction of people in homes to sonic booms and to the noise from subsonic aircraft.

1. Vibration Isolation

For one series of 16 missions about half the subjects in houses E-1 and E-2 and about half the subjects outdoors sat on chairs placed on a piece of plywood that was isolated from the ground or the floor by an air-inflated pad 1-12 inches in diameter (the floors were carpeted in all rooms but the kitchen, where the flooring was covered with vinyl tile). Each subject sat on a vibration-isolated chair during half the tests, and on a normal, nonvibration-isolated chair during the other half.

Figure 23 shows that the vibration isolation had no significant effects on the ratings given to the booms or the aircraft noise, although there is a slight statistically insignificant improvement in the acceptability of the boom when the subjects were indoors and on the vibration-



GROUP	NOT ISOLATED	ISOLATED	NET CHANGE
a (INDOORS)	115.0 PNdB	114.5 PNdB	-0.5 PNdB
b (INDOORS)	113.5 PNdB	113.0 PNdB	-0.5 PNdB
c (OUTDOORS)	111.0 PNdB	111.0 PNdB	0 PNdB

FIG. 23 RESULTS OF PAIRED-COMPARISON JUDGMENTS SHOWING INSIGNIFICANT ISOLATION EFFECTS. Doto ore Peok PNdB levels of subsonic oircroft noise judged to be os acceptable os B-58 boom of 2.33 psf nominol peok overpressure.

isolation pads. This finding is perhaps somewhat unexpected because in many locations within the house the subjects and the experimenters could "feel" the floor shake when the house was subjected to sonic booms; at the same time, however, they could hear the sounds made in the house as the result of its being vibrated by the boom. It would appear that the auditory component was nearly as or perhaps slightly more effective than the actual vibrations as felt by the subjects in determining their response to the sonic booms and noise from the subsonic aircraft.

2. House Loading

When all the subjects were in place, an average of 32 in each house, more than a typical (for a single-family residence) number of persons were present in the test houses. To test whether the weight of the people so loaded the structures that the houses did not respond to the booms in a normal manner, one series of tests was run with onl an average of ten subjects in each test house. The results were essentially the same for comparable boom and noise exposures when ten subjects or when 32 subjects were in a house.

H. Mail Survey Ratings of Sonic Booms, Aircraft Noise, and Street Noise by Residents of Edwards AF Base

Residents of Edwards AF Base were asked on 1 July 1966 to rate several noise conditions present in or around their homes on a scale similar to that used by the test subjects: (1) during the month of June when the special sonic boom tests were being conducted, and (2) for the months prior to June. It is estimated that an average daily number of sonic booms at Edwards during the month of June 1966 was about ten (the residents estimated six). It is seen in Table 17 that 26 percent of the people who answered the mail survey felt that the sonic boom environment at Edwards during the month of June was unacceptable.

Street noise and the noise of subsonic aircraft would appear to be no significant problem to the residents at Edwards AF Base. It should be borne in mind that although occasionally the noise of low-flying subsonic aircraft reaches the residential area at Edwards, the normal take-off and approach paths to the runways avoid the residential area and

Table 17

MAIL SURVEY DATA: PERCENTAGE OF PERSONS WHO RATED SONIC BOOMS AND NOISE AS UNACCEPTABLE (LESS THAN "JUST ACCEPTABLE")

Type	Response Total	Male	Female	Age				Time-on-Base			
				<25	25-34	35-44	>44	<0.5	0.5-1	1-5	>5
Street Noise, June	7%	9%	5%	6%	6%	8%	5%	7%	5%	8%	4%
Aircraft Noise, June	6	6	6	10	6	4	7	5	7	5	7
Aircraft Noise, Prior	3	3	4	5	3	3	3	1	5	3	0
Sonic Boom, June	26	25	27	37	25	25	21	28	27	25	20
Sonic Boom, Prior	14	13	15	16	13	11	18	13	17	11	16
Number of Persons Who Responded	783*	353	397	90	366	238	78	109	249	371	46

* Includes 33 families with no designation of male or female response. Age was not reported for 11 responses. Time-on-base was not reported for eight responses.

the flight path of the subsonic aircraft used in the sonic boom evaluation tests did not pass over the residential areas. Figure 24 shows distributions for the ratings of different environmental noises by a sample of the residents of Edwards AF Base.

Figure 25 depicts the acceptability ratings of environmental noises made by residents of Edwards AF Base as a function of their age and years of residence at Edwards. It would appear from this figure that, particularly with respect to sonic booms, the older the person and the longer he or she had lived there, the more acceptable were the noises. Age and years of residence are obviously not independent of each other, and an analysis of the data by years of residence, keeping age constant, showed no consistent influence of age upon the ratings of sonic booms. (See Table 17.) No significant difference was found between the results of paired-comparison tests and ratings for different age groups of subjects. (see Tables 8 and 9.)

The respondents rated the sonic boom as the least acceptable noise condition at Edwards as follows:

Least Acceptable Condition	No. Replies	Percent
Sonic Boom	553	71
Street Noise	135	17
Airplane Noise	90	12

These data obviously substantiate the displacement between the curves for these various noise conditions shown in Fig. 25.

Some adaptation, as mentioned above, to the sonic booms is evident from data given in Fig. 25. This is further demonstrated by the answers (tabulated below) to the question, "Do you think living at Edwards AF Base and being regularly exposed to sonic booms in your homes up to 1 June 1966 has tended to make sonic booms when heard in your home to be:"

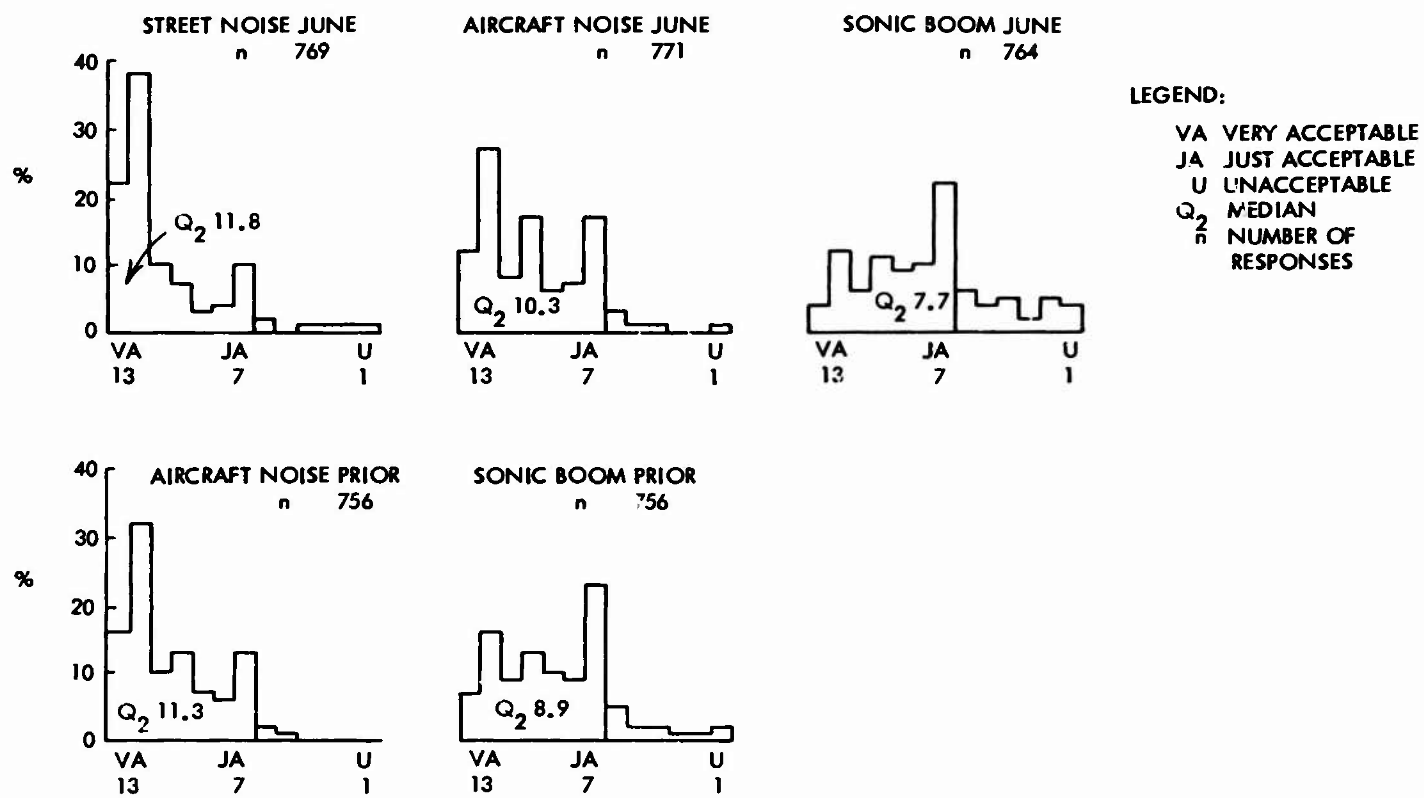
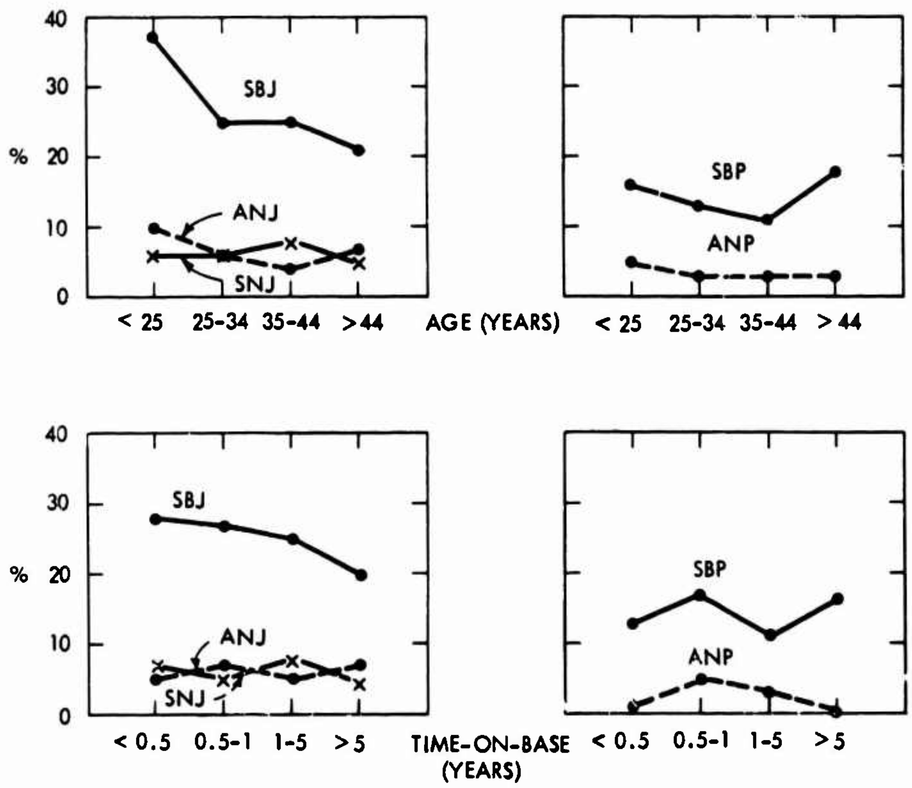


FIG. 24 DISTRIBUTION OF ACCEPTABILITY RATINGS OBTAINED BY MAIL SURVEY



SBJ SONIC BOOM, JUNE
ANJ AIRCRAFT NOISE, JUNE
SNJ STREET NOISE, JUNE
SBP SONIC BOOM, PRIOR
ANP AIRCRAFT NOISE, PRIOR

FIG. 25 PERCENTAGE OF PERSONS WHO RATED SONIC BOOMS AS UNACCEPTABLE (Less than just acceptable). Data obtained by mail survey.

Living at Edwards Made Boom	No. Replies	Percent
More acceptable	456	60
No change	246	33
Less acceptable	53	7

At the same time it should be noted, as shown in Table 17, that about 14 percent of the people who replied to the mail questionnaire rated in retrospect the sonic boom conditions prior to the month of June as being unacceptable, compared to 26 percent who rated the booms heard during June as being unacceptable. Part of the explanation for this difference undoubtedly was due to the difference in boom exposures during these periods. The average nominal peak overpressure of sonic booms during a typical operational month prior to June 1966 in the residential area of Edwards is about 1.2 psf and the average frequency about four to eight per day. During the month of June, however, about 289 booms were created, giving a daily average of about ten and a median nominal peak overpressure of about 1.69 psf.

IV SUMMARY OF FINDINGS

Major findings from analysis of the results obtained for the subjects and listening conditions involved in these experiments are as follows:

1. Sonic Boom from B-58 Judged Against Noise from Subsonic Aircraft

   (a) When indoors, subjects from Edwards AF Base judged booms from the B-58 at 1.69 psf nominal peak overpressure outdoors to be as acceptable as the noise from a subsonic jet at an intensity of 109 PNdB* measured outdoors.

   (b) When indoors, subjects from the towns of Fontana and Redlands judged the boom from the B-58 at 1.69 psf nominal peak overpressure outdoors to be as acceptable as the noise from a subsonic jet at an intensity of 118 to 119 PNdB** measured outdoors.

   (c) The booms heard outdoors from the B-58 at 1.69 nominal peak overpressure were judged to be as acceptable as the noise heard outdoors from a subsonic jet at 105 PNdB, 111 PNdB, and 108 PNdB by subjects from Edwards AF Base, Fontana, and Redlands, respectively.

   (d) When indoors, 27 percent of the subjects from Edwards and 40 percent of the subjects from Fontana and Redlands

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*Noises having these PNdB values would be generated on the ground directly under the flight path of a turbofan aircraft at an altitude of 800 or 1400 ft, depending on whether landing or takeoff engine power settings were used.

**Noises having these PNdB values would be generated on the ground directly under the flight path of a turbofan aircraft at an altitude of 300 or 600 ft, depending on whether landing or takeoff engine power settings were used.

combined rated the B-58 booms of nominal peak overpressure of 1.69 psf as being between less than "just acceptable" to "unacceptable."

(e) When outdoors, 33 percent of the subjects from Edwards and 39 percent of the subjects from Fontana and Redlands combined, rated the B-58 booms of nominal peak overpressure of 1.69 psf as being between less than "just acceptable" to "unacceptable."

(f) Residents of Edwards AF Base who served as subjects had been in residence there for an average of two years and had been exposed during that period to about four to eight booms per day of median nominal peak overpressure of 1.2 psf and to subsonic aircraft noise occasionally having Peak PNdB levels as high as 110 PNdB. The towns of Fontana and Redlands, on the other hand, were not under or near the flight track of supersonic aircraft and were occasionally exposed to subsonic aircraft at a peak level of about 95-100 PNdB.

2. Acceptability of Sonic Booms from Different Military Aircraft

(a) When heard indoors and judged against the aircraft noise, the booms from the XB-70, B-58, and F-104 were for comparable peak overpressures, equally acceptable. When heard outdoors and judged against aircraft noise, the boom from the B-58 was slightly less acceptable than the booms from the XB-70 and F-104 aircraft.

(b) When one type of boom was judged against another type of boom at equal nominal peak overpressure, no consistent significant difference in their acceptability was measured in these tests.

3. Acceptability of Booms and Aircraft Noise as a Function of Their Intensity

The unacceptability of sonic booms, as a function of intensity, increases at about twice again as fast a rate as does the unacceptability of

of the noise from subsonic aircraft; i.e., in terms of judged unacceptability, an increase of 12 PNdB in intensity of a noise from a subsonic aircraft was equivalent to about a 6 dB increase (from 1 psf to 2 psf) in the intensity of a sonic boom.

4. Acceptability of Booms or Noises for Indoor Listening Compared to Outdoor Listening

The results averaged over all tests indicates that the booms and particularly the noise were rated slightly more unacceptable by the listeners outdoors than by the listeners indoors. Also, the precision of the judgments and rate of growth of unacceptability as a function of the intensity of the booms or noise was about 50 percent greater for listeners outdoors than indoors.

5. Relations Between Physical Measures of Sonic Booms and Judgments of Acceptability

Energy band spectral analyses of the booms showed that the energy in the band 20-200 Hz or 20-1000 Hz predicted the subjective judgments of the listeners located both outdoors and indoors as well as overall peak overpressure. The maximum contribution to the Perceived Noise Level in PNdBs calculated for the sonic booms from the F-104, B-58, and XB-70 is made in the frequency region from 20-500 Hz or so and is negligible below 20 Hz and above 500 Hz.

6. Relations Between Physical Measures of Subsonic Aircraft Noise and Judgments of Acceptability

The following physical measures or calculated values from the physical measures are listed in the rank order, from best to worst, with which they predicted the judged acceptabilty of the takeoff and landing approach noise from the turbojet and turbofan subsonic jet aircraft used for these tests:

Indoor - $EPNdB_t$, EPNdB, Max Phons, dB(A), dB(N), Max PNdB, Peak $PNdB_t$, EEPNdB, Peak PNdB, Max $PNdB_t$, $EEPNdB_t$, dB(B), dB(C)

Outdoor - $EPNdB_t$, $EEPNdB_t$, EEPNdB, Max PNdB, EPNdB, Peak PNdB, Max Phons, dB(N), Max $PNdB_t$, Peak $PNdB_t$, dB(A), dB(C), dB(B)

7. Discrimination of Intensity Differences in Booms and Subsonic Aircraft Noise

(a) On the average, two booms were judged relative to each other to be significantly different in acceptability when their nominal or measured peak overpressures differed by about 1 dB, and by about 2 dB when the two booms were compared indirectly by judging each against a reference aircraft noise.

(b) On the average, two aircraft noises were judged relative to each other to be significantly different in acceptability when they differed by about 2 PNdB, and by about 3 PNdB when the two aircraft noises were compared indirectly by judging each against a reference boom.

8. Differences in Judgments of Subjects Located in Different Rooms and When on Vibration Isolation Pads

Systematic differences were found among some of the subgroups of subjects located in different rooms in the test houses. When some of the subjects were exchanged among rooms, it was found that some of the differences were due to the test rooms and not to the subjects. The F-104 boom caused less displacement of at least some of the walls in the test houses than did the booms from the B-58 or XB-70 which caused about equal displacement.

Placing the indoor and outdoor subjects on vibration isolation pads did not significantly change their judgments of the sonic booms relative to the noise from the subsonic aircraft.

9. Attitude Survey

An attitude survey of residents (15 percent of whom served as subjects in these experiments) at Edwards AF Base revealed that 26 percent rated the boom environment as being between less than "just acceptable" to "unacceptable" for the month of June, when there was an average of about ten booms per day at a median nominal peak overpressure of about 1.69 psf. Fourteen percent of the residents also rated the boom

environment prior to June as being between less than "just acceptable" to "unacceptable." During this previous period, there were about four to eight booms per day at a median nominal boom level of 1.2 psf. Six percent rated the ambient daily aircraft noise and seven percent rated the street noise as being between less than "just acceptable" to "unacceptable."

10. Age and Sex of Subjects

Within the adult population studied, age and sex are not statistically significant factors in the ratings or paired-comparison of the unacceptability of sonic booms or the aircraft noises.

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Appendix A

MISSIONS FOR PSYCHOLOGICAL TESTS

Table A-1

EDWARDS - PHASE I

Experiment 1: BOOM vs BOOM
B-58 versus B-58
F-104 versus F-104
B-58 versus F-104

Missions*	A/C	Altitude kft. MSL**	MACH	Lat. Dist. Miles	Nominal Peak Overpressure (POP) (psf)
18-A, 21-A, 29-B, 32-B	B-58	36	1.65	0	2.33
18-B, 21-B, 29-A, 32-A	B-58	48	1.65	0	1.69
1X-A, 4X-A, 2X-B, 3X-B	F-104	13	1.3	0	3.30
1X-B, 4X-B, 2X-A, 3X-A	F-104	28	1.65	0	1.5
26-A, 26(R)-A, 37-A, 38-B, 27-B	F-104	20	1.4	0	1.85
26-B, 26(R)-B, 37-B, 38-A, 27-A	F-104	28	1.65	0	1.5
17-A, 28-A, 31-A, 20-B, 36-B	B-58	36	1.65	0	2.33
17-B, 28-B, 31-B, 20-A, 36-A	F-104	20	1.4	0	1.85
19-A, 30-A, 23-B	B-58	36	1.65	0	2.33
19-B, 30-B, 23-A	F-104	28	1.65	0	1.5
24-A, 35-A, 25-B	B-58	42	1.65	5.	1.69
24-B, 35-B, 25-A	F-104	20	1.40	0	1.85
22-A, 34-A, 33-B	F-104	28	1.65	0	1.5
22-B, 34-B, 33-A	B-58	42	1.65	5.	1.69

* A is first aircraft of pair; B flown second.
** Local altitude is 2300 ft.
(R) Indicates the mission was repeated with the same number.

Table A-1 (cont'd)

EDWARDS - PHASE I

Experiment 2: BOOM vs NOISE
B-58 vs KC-135

Missions*	A/C	Alt. kft. MSL**	MACH	Lat. Dist. Miles	Nom. POP (psf)	Alt. kft. MSL**	EPR	Est. PNdB
39-A, 55R-B, 55SR-B	B-58	42	1.65	5	1.69			
39-B, 55R-A, 55SR-A	KC-135					10.3	1.5	88
40-A, 40(R)-A, 48-A, 48(R)-A, 56R-B, 56SR-B	B-58	42	1.65	5	1.69			
40-B, 40(R)-B, 48-B, 48(R)-B, 56R-A, 56SR-A	KC-135					5.3	1.5	98
41-A, 41(R)-A, 41S-A, 57R-B, 57SR-B	B-58	42	1.65	5	1.69			
41-B, 41(R)-B, 41S-B, 57R-A, 57SR-A	KC-135					3.3	1.5	108
42-A, 42(R)-A, 42S-A, 42S(R)-A, 58-B, 66-B	B-58	42	1.65	5	1.69			
42-B, 42(R)-B, 42S-B, 42S(R)-B, 58-A, 66-A	KC-135					2.8	1.5	114
43-A, 43(R)-A, 43S-A, 59-B	B-58	42	1.65	5	1.69			
43-B, 43(R)-B, 43S-B, 59-A	KC-135					14.3	2.35	95
50-A, 44R-A, 60-B, 60(R)-B, 68-B	B-58	42	1.65	5	1.69			
50-B, 44R-B, 60-A, 60(R)-A, 68-A	KC-135					8.3	2.35	101
49-A, 53-A, 61-B, 69-B	B-58	42	1.65	5	1.69			
49-B, 53-B, 61-A, 69-A	KC-135					4.3	2.35	111
46S-A, 48(R)-A, 54-A, 45R-B, 46R-B	B-58	42	1.65	5	1.69			
46S-B, 48(R)-B, 54-B, 45R-A, 46R-A	KC-135					3.0	2.35	121

* A is first aircraft of pair; B is flown second.
** Local altitude is 2300 ft.
(R) Indicates the mission was repeated with the same number.

Table A-1 (cont'd)

EDWARDS - PHASE I

Experiment 2: BOOM vs NOISE
(continued) B-58 vs KC-135

Missions*	A/C	Alt. kft. MSL**	MACH	Lat. Dist. Miles	Nom. POP (psf)	Alt. kft. MSL**	EPR	Est. PNdB
70-A, 86R-B, 86SR-B	B-58	30	1.5	0	2.65			
70-B, 86R-A, 86SR-A	KC-135					5.3	1.5	98
71-A, 79-A, 87R-B, 87SR-B	B-58	30	1.5	0	2.65			
71-B, 79-B, 87R-A, 87SR-A	KC-135					3.3	1.5	108
72-A, 72(R)-A, 72S-A, 72S(R)-A, 80R-B, 80SR-B	B-58	30	1.5	0	2.65			
72-B, 72(R)-B, 72S-B, 72S(R)-B, 80R-A, 80SR-A	KC-135					2.8	1.5	114
73-A, 73(R)-A, 73S-A, 89-B	B-58	30	1.5	0	2.65			
73-B, 73(R)-B, 73S-B, 89-A	KC-135					2.55	1.5	120
74-A, 90-B, 98-B	B-58	30	1.5	0	2.65			
74-B, 90-A, 98-A	KC-135					8.3	2.35	101
75-A, 75(R)-A, 81(RR)-A, 75S-A, 76R-B, 99-B	B-58	30	1.5	0	2.65			
75-B, 75(R)-B, 81(RR)-B, 75S-B, 76R-A, 99-A	KC-135					4.3	2.35	111
80-A, 84-A, 77R-B, 100-B	B-58	30	1.5	0	2.65			
80-B, 84-B, 77R-A, 100-A	KC-135					3.0	2.35	121
79-A, 85-A, 85(R)-A, 93-B, 101-B	B-58	30	1.5	0	2.65			
79-B, 85-B, 85(R)-B, 93-A, 101-A	KC-135					2.6	2.35	128

* A is first aircraft of pair; B is flown second.
** Local altitude is 2300 ft.
(R) Indicates the mission was repeated with the same number.

Table A-1 (concluded)

EDWARDS - PHASE I

Experiment 3: NOISE vs NOISE

KC-135 vs WC-135B

Missions*	A/C	Alt. kft. MSL**	EPR	Est. PNdB
1-A, 12-B	KC-135	3.1	1.5	108
1-B, 12-A	WC-135B	2.55	1.3	121
2-A, 11-B	KC-135	3.1	1.5	108
2-B, 11-A	WC-135B	3.05	1.3	113
3-A, 10-B	KC-135	3.1	1.5	108
3-B, 10-A	WC-135B	3.8	1.3	104
6-A, 7-B	KC-135	3.1	1.5	108
6-B, 7-A	WC-135B	2.55	1.76	125
5-A, 8-B	KC-135	3.1	1.5	108
5-B, 8-A	WC-135B	3.05	1.76	117
4-A, 9-B	KC-135	3.1	1.5	108
4-B, 9-A	WC-135B	3.8	1.76	108
15-A, 22-B	KC-135	4.3	2.35	112
15-B, 22-A	WC-135B	2.55	1.3	121
14-A, 23-B	KC-135	4.3	2.35	112
14-B, 23-A	WC-135B	3.05	1.3	113
13-A, 24-B	KC-135	4.3	2.35	112
13-B, 24-A	WC-135B	3.8	1.3	104
16-A, 21-B	KC-135	4.3	2.35	112
16-B, 21-A	WC-135B	2.55	1.76	125
17-A, 20-B	KC-135	4.3	2.35	112
17-B, 20-A	WC-135B	3.05	1.76	117
18-A, 19-B	KC-135	4.3	2.35	112
18-B, 19-A	WC-135B	3.8	1.76	108

* A is first aircraft of pair; B is flown second.

** Local altitude is 2300 ft.

Table A-2

EDWARDS - PHASE II

Experiment 1: **BOOM VS BOOM**

XB-70 versus B-58

F-104 versus B-58

Missions*	A/C	Altitude kft. MSL**	MACH	Lat. Dist. Miles	Nominal Peak Overpressure (POP) (psf)
1-A, 2-A, 3-B, 4-B	XB-70	37	1.5	0	2.52
1-B, 2-B, 3-A, 4-A	B-58	32	1.5	0	2.52
9-A, 10-A, 11-B, 12-B	XB-70	60	2.5	0	2.06
9-B, 10-B, 11-A, 12-A	B-58	40	1.65	0	2.06
13-B, 113-B, 14-A, 15-A, 16-B	XB-70	60	1.8	0	2.06
13-A, 113-A, 14-B, 15-B, 16-A	B-58	40	1.65	0	2.06
17-A, 18-B, 19-A, 20-B	F-104	30.5	1.65	0	1.69
17-B, 18-A, 19-B, 20-A	B-58	48	1.65	0	1.69
117-A, 118-B	F-104	26.1	1.65	0	1.69
117-B, 118-A	B-58	48	1.65	0	1.69

* A is first aircraft of pair; B is flown second.

** Local altitude is 2300 ft.

Table A-2 (cont'd)

Experiment 2: **BOOM VS NOISE** EDWARDS - PHASE II

F-104 vs C-135B
XB-70 vs C-135B

Missions*	A/C	Alt. kft. MSL**	MACH	Lat. Dist. Miles	Nom. POP (psf)	Alt. kft. MSL**	EPR	Est. PNdB
52-A, 57-A, 51-B, 58-B	F-104	16.3	1.3	0	2.8			
52-B, 57-B, 51-A, 58-A	C-135B					2.65	1.76	125
54-A, 55-A, 49-B, 60-B	F-104	16.3	1.3	0	2.8			
54-B, 55-B, 49-A, 60-A	C-135B					2.9	1.76	119
53-A, 56-A, 50-B, 59-B	F-104	16.3	1.3	0	2.8			
53-B, 56-B, 50-A, 59-A	C-135B					3.4	1.76	113
61-A, 67-A, 66-B, 172-B	F-104	29.5	1.65	0	1.4			
61-B, 67-B, 66-A, 172-A	C-135B					3.4	1.76	113
62-A, 68-A, 65-B, 71-B, 72-B	F-104	29.5	1.65	0	1.4			
62-B, 68-B, 65-A, 71-A, 72-A	C-135B					4.4	1.76	105
63-A, 69-A, 64-B, 70-B	F-104	29.5	1.65	0	1.4			
63-B, 69-B, 64-A, 70-A	C-135B					6.4	1.76	95
73-A, 79-A, 78-B, 84-B	F-104	50	1.5	0	0.7			
73-B, 79-B, 78-A, 84-A	C-135B					4.4	1.65	105
74-A, 80-A, 77-B, 83-B	F-104	50	1.5	0	0.7			
74-B, 80-B, 77-A, 83-A	C-135B					6.4	1.76	95
75-A, 81-A, 76-B, 82-B	F-104	50	1.5	0	0.7			
75-B, 81-B, 76-A, 82-A	C-135B					10.4	1.76	85
5-A, 6-A, 7-B, 8-B	XB-70	60	2.5	13	1.36			
5-B, 6-B, 7-A, 8-A	C-135B					3.7	1.76	110

* A is first aircraft of pair; B is flown second.
** Local altitude is 2300 ft.

Table A-2 (cont'd)

EDWARDS - PHASE II

Experiment 3: BOOM VS NOISE
B-58 vs C135-B

Response of Non-Air Force Base Subjects

Missions*	A/C	Altitude kft. MSL**	MACH	Lat.Dist. Miles	Nom.PCP (psf)	Alt. kft. MSL**	EPR	Est. PNdB
FONTANA								
21-A,121-A , 24-A, 29-B, 32-B	B-58	48	1.65	0	1.67			
21-B,121-B , 24-B, 29-A, 32-A	C135-B					5.2	1.76	101
22-A, 25-A, 28-B, 31-B	B-58	48	1.65	0	1.67			
22-B, 25-B, 28-A, 31-A	C135-B					3.8	1.76	109
23-A, 26-A, 27-B, 30-B	B-58	48	1.65	0	1.67			
23-B, 26-B, 27-A, 30-A	C135-B					3.1	1.76	116
REDLANDS								
221-A, 124-A, 129-B, 132-B	B-58	48	1.65	0	1.67			
221-B, 124-B, 129-A, 132-A	C135-B					4.2	1.76	106
122-A, 125-A, 128-B, 131-B	B-58	48	1.65	0	1.67			
122-B, 125-B, 128-A, 131-A	C135-B					3.4	1.76	113
123-A, 126-A, 127-B, 130-B	B-58	48	1.65	0	1.67			
123-B, 126-B, 127-A, 130-A	C135-B					2.8	1.76	120

* A is first aircraft of pair; B is second.

** Local altitude is 2300 ft.

Table A-2 (concluded)

EDWARDS - PHASE II

Experiment 4: **BOOM VS NOISE**
Isolation, Exchange, and Loading
B-58 versus C-135B

Missions*	A/C	Altitude kft. MSL**	MACH	Lat. Dist. Miles	Nom. POP (psf)	Alt. kft. MSL**	EPR	Est. PNdB
(1) 33-A, 36-A, 37-B, 40-B (2) 42-A, 46-A, 43-B, 47-B (3) 87-A, 88-A, 85-B, 86-B	B-58	36	1.65	0	2.33			
(1) 33-B, 36-B, 37-A, 40-A (2) 42-B, 46-B, 43-A, 47-A (3) 87-B, 88-B, 85-A, 86-A	C-135B					3.2	1.76	115
(1) 34-A, 35-A, 38-B, 39-B (2) 41-A, 45-A, 44-B, 48-B	B-58	36	1.65	0	2.33			
(1) 34-B, 35-B, 38-A, 39-A (2) 41-B, 45-B, 44-A, 48-A	C-135B					4.4	1.76	105

CONDITIONS

Normal Location of Group	(1)	(2)	(3)
E1 Bedroom (1B)	In 2L	Normal	Approx. 1/3 indoor, remainder outdoor
E1 Living Room (1L)	Approx. half on isolation pads	Normal for Mission 41*	
E1 Kitchen (1K)	Outdoors	Normal	
E2 Bedroom (2B)	Approx. half on isolation pads	Normal for Mission 41*	**
E2 Living Room (2L)	In 1B	Normal	
E2 Dining Room (2D)	Approx. half on isolation pads	Normal for Mission 41*	
E2 Family Kitchen (2K)	Approx. half on isolation pads	Normal for Mission 41*	
Outdoor (T1 and T2)	Part of group in 1K. Approx. half of remainder on isolation pads.	Normal	Normal

Changes in Experimental Design

None for aircraft requirements.

*Approximately one-half the people in 1L, 2B, 2D, and 2K (those not isolated under condition (1) were placed on isolation pads for Missions 42-48.

**Due to an oversight, the entire 2B group was indoors for Missions 87 and 88.

Appendix B

INSTRUCTIONS TO SUBJECTS

Appendix B

SONIC BOOM JUDGMENT TESTS

It is anticipated that in the not too distant future supersonic transports, which create sonic booms, will be placed into commercial operation. The study in which you are participating is being conducted to determine what kinds of sonic booms, if any, are the most acceptable to people.

As you know, special supersonic aircraft operate from Edwards Air Force Base. These aircraft occasionally generate "sonic booms" with which you are familiar. Because you are somewhat familiar with sonic booms and because they are generated as a matter of everyday operation at Edwards Air Force Base, we would like you to make certain judgments about the relative acceptability of the sonic booms that you will hear during this study.

The sonic booms you will hear will be of the intensity that normally occur at or near Edwards Air Force Base during everyday operations and are levels which will presumably be present in communities when the anticipated commercial supersonic aircraft fly across the United States.

There is nothing secret or classified about these tests. However, we ask that you do not attempt to give opinions about the results of the tests inasmuch as the results will not be analyzed or understood until the study is completed and all data are given proper consideration. Also, you should not discuss, in particular, your reactions to these sounds with your fellow observers inasmuch as we want your own opinions, and we expect people to differ in their judgments. There are no right or wrong answers.

These tests are being conducted jointly by the Air Force, the National Aeronautics and Space Administration, and the Federal Aviation Agency, and are part of the program for the development of a commercial supersonic transport. Your concientious participation in this program is greatly appreciated. Any requests for additional information should be addressed to: Public Information Officer, Edwards Air Force Base.

P

DATE MONTH

LAST NAME INITIAL

LOC. ISO.

CIRCLE **A** IF FIRST SOUND IS MORE ACCEPTABLE.
CIRCLE **B** IF SECOND SOUND IS MORE ACCEPTABLE.

1.	A	B
2.	A	B
3.	A	B
4.	A	B
5.	A	B
6.	A	B
7.	A	B
8.	A	B
9.	A	B
10.	A	B
11.	A	B
12.	A	B
13.	A	B
14.	A	B
15.	A	B
16.	A	B
17.	A	B
18.	A	B
19.	A	B
20.	A	B

INSTRUCTIONS:

The primary purpose of the tests being conducted is to determine, if possible, how people feel about the *relative* acceptability of one type or level of aircraft noise when compared with a second type or level of aircraft noise.

You will hear a series of sounds from aircraft. Some of the sounds will be sonic booms and some will be the sound made by a subsonic jet aircraft. The sounds will occur in "pairs" and your task is to judge which sound in each pair you think would be more acceptable to you if heard in or near your home during the day and/or evening when you are engaged in typical, awake activities.

After you have heard each pair of sounds please quickly decide which of the two you feel would be more acceptable to you. If you think the second sound of a pair would be more acceptable, circle **B** for that particular pair. If you think the first sound in the pair would be more acceptable to you than the second, circle **A**.

Please concentrate on the judgment at hand and give an answer even though the two sounds may seem approximately equal in acceptability to you. If you feel that there is absolutely no real difference in terms of acceptability of the two sounds, please circle either **A** or **B**, giving the best guess you can, and put a question mark after that pair.

There are no "right" or "wrong" answers, nor do we expect people to agree with each other. We are interested in how *you* feel about the sounds and how people differ in their judgments of the acceptability of these aircraft sounds.

An announcement will be made before each pair of sounds is to occur.. The sounds of a pair may be separated in time by several minutes; usually, however, they will occur within a single minute. During this period we ask that you be quiet and attentive. Give us your best judgment and imagine, if you will, that you are listening to these sounds in or near your own home.

LAST NAME INITIAL

R DATE MONTH LOC. ISO.

For each aircraft noise you hear, indicate with an X in the corresponding box how you would feel if you heard this noise in or near your home 10 - 15 times throughout the day and evening.

1. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

2. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

3. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

4. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

5. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

6. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

7. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

8. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

9. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

10. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

11. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

12. A
B
VERY ACCEPTABLE JUST ACCEPTABLE UNACCEPTABLE

NAME

LAST NAME

FIRST NAME

MIDDLE INITIAL

SOCIAL SECURITY NUMBER:

			—			—				

PLACE OF PRESENT RESIDENCE (Circle One):

B	N
On Base	Off Base

MARITAL STATUS (Circle One):

M	S
Married	Not Married

SEX (Circle One):

M	F
Male	Female

AGE:

OCCUPATION (Circle One):

H	A	R	O
Housewife	Air Force Employee	Retired	Other

HUSBAND EMPLOYED BY (Circle One): Military Civilian

IF MILITARY, STATE RANK: ______________________________

TIME IN AREA TO THE NEAREST YEAR (Circle One):

L	1	2	3	4	5	6
Less than 6 months	1 yr.	2 yrs.	3 yrs.	4 yrs.	5 yrs.	6 yrs. or more

ADDRESS:

STREET ADDRESS

C	a	l	i	f	.					

ZIP CODE

Appendix C

ATTITUDE SURVEY

Appendix C

ATTITUDE SURVEY

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS, AIR FORCE FLIGHT TEST CENTER (AFSC)
EDWARDS AIR FORCE BASE, CALIF. 93523

OFFICE OF
THE COMMANDER

7 June 1966

SUBJECT: Sonic Boom Testing Program

TO All Occupants, Base Housing

1. Edwards AFB has been chosen as a place to study some of the reactions and feelings people have to the noise of subsonic aircraft and to sonic booms. Edwards was chosen because it is a base where people are exposed to the noise of aircraft and to sonic booms.

2. These studies are a joint Air Force, NASA and FAA project with Stanford Research Institute assisting as a government contractor. The studies are an important step to finding out which types of sonic booms and other noises are bothersome to people. The program is directly related to design and development of commercial supersonic transport aircraft. Sonic booms created by these aircraft must be socially acceptable to the people of the United States.

3. There are obviously no "right" or "wrong" answers to the questions on the enclosed sheet. It is your opinion and first reaction to each question that is wanted. It is expected that people will differ widely in their opinions.

4. The individual (not joint) opinions of the husband and of the wife, to be given separately on the enclosed answer sheets, are requested. If one of you cannot fill out the answer sheet, or objects to doing so, please send in at least one answer sheet completed. The answer sheets are numbered to aid in data analysis, but the identification of persons filling out the answer sheets will not be used in any way or kept. You will also be asked to complete answer sheets like the enclosed one once or possibly twice again later this summer.

5. This is a voluntary service we are asking you to perform. The program has the full endorsement of the Air Force and is important. For these reasons, your willing cooperation and participation will be appreciated.

Hugh B. Manson

HUGH B. MANSON
Brigadier General, USAF
Commander

Please return this answer sheet within a few days in the enclosed addressed envelope.

Please check one point on each of the lines below which indicates most closely how you felt on the average in your present home during the past few weeks or month about the kinds of various sounds indicated.

a. The sounds, as heard in your home during the day and night for the past few weeks or month, of aircraft flying overhead or nearly so shortly after taking off or during approach to landing were on the average:

Very Acceptable — Just Acceptable — Unacceptable

b. The sonic booms, as heard in your home during the day and night for the past few weeks or month, were on the average:

Very Acceptable — Just Acceptable — Unacceptable

c. Street noises, as heard in your home during the day and night for the past few weeks or month, were on the average:

Very Acceptable — Just Acceptable — Unacceptable

Please check what you think was the number of occurences of the following sounds, as heard in your home during the average day and night, for the past several weeks or month:

a. The sounds of aircraft flying overhead or nearly so shortly after taking off or during approach to landing.

Approximate Average No. of Daily Occurences

1 or Less	2 - 5	6 - 10	11 - 20	21 - 30	30 or More

b. Sonic Booms

Approximate Average No. of Daily Occurences

1 or Less	2 - 5	6 - 10	11 - 20	21 - 30	30 or More

Please place a circle around the condition which in your present home is the most bothersome or least acceptable to you:

a. general airplane noise   b. sonic booms   c. street noise

How long have you lived at Edwards Air Force Base? ________ Your age? ________

Please check: husband ________ wife ________

The previous page was concerned with your reaction to sonic booms during the first three weeks or so of the month of June 1966. The questions below are about how you felt about sonic booms and aircraft noise at Edwards Air Force Base before 1 June 1966.

---

1. Do you think that the sounds of aircraft flying overhead shortly after taking off or during approach to the landing you have heard in your home, up to about 1 June 1966, while living at Edwards Air Force Base were, on the average:

Very Acceptable — Just Acceptable — Unacceptable

---

2. Do you think that the sonic booms you have heard in your homes, up to about 1 June 1966, while living at Edwards Air Force Base were, on the average:

Very Acceptable — Just Acceptable — Unacceptable

---

3. Do you think that living at Edwards Air Force Base and being regularly exposed in your homes to sonic booms up to about 1 June 1966 has tended to make sonic booms when heard in your home to be:

   a) more acceptable /__/
   b) no change /__/ (Please check one box)
   c) less acceptable /__/

---

4. Do you think that living at Edwards Air Force Base and being regularly exposed in your homes to the sounds of aircraft flying overhead shortly after taking off or during landing up to about 1 June 1966 has tended to make these sounds when heard in your home to be on the average:

   a) more acceptable /__/
   b) no change /__/ (Please check one box)
   c) less acceptable /__/

Please return this answer sheet, along with the attached sheet, within a few days in the enclosed, addressed envelope.

Attach.

Appendix D

VARIABILITY IN PAIRED-COMPARISON TESTS

Appendix D

VARIABILITY IN PAIRED-COMPARISON TESTS

The following factors are considered to be possible major sources of unwanted variability in the present tests:

1. Variations in the attentiveness and attitudes of the subjects from moment to moment

2. Chance variation in the physical conditions, such as the aircraft being slightly off flight course or prescribed power setting, or effects of weather conditions on the booms, the presence of extraneous noises, etc.

3. The fact that, at the intensity levels used in these tests, the second sound to be judged in a pair is usually found to have a somewhat stronger psychological effect on a person than the first sound, even though they are physically equal (the so-called "time-error" in judgment tests).

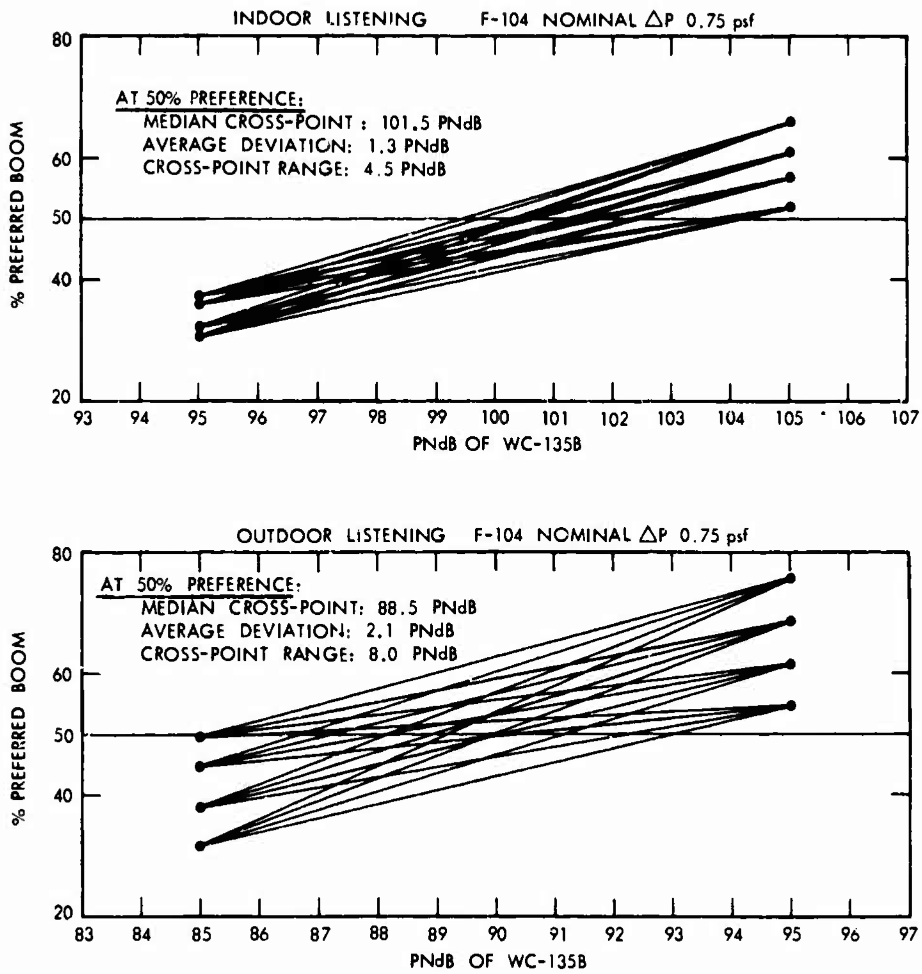
The tests were designed to reduce to a practical minimum the effects of these factors on the results by having the subjects judge each pair of sounds four times: twice in the order of sound A followed by sound B, and twice in the order sound B followed by sound A. In addition, the sequencing of pairs for any one test condition was randomized insofar as flight operations would permit among all test conditions and testing days. The average of the results taken over the four judgments for any two sounds that were compared with each other represents then the best estimate possible of the relative subjective acceptability of the two sounds, taking into account the error-factors outlined above.

An estimate can be made of the variability that would be expected had only one set of A-B and B-A pairs been given for each test condition. This can be done by finding the 50-percent crossing points for the various test conditions from curves based on each possible A-B and B-A data point, rather than on the average of all four pairs, as was done in

Figures 1 through 5 in the main text. Figures D-1 through D-3 show the data for the F-104 vs. WC-135B pairs plotted in this way.

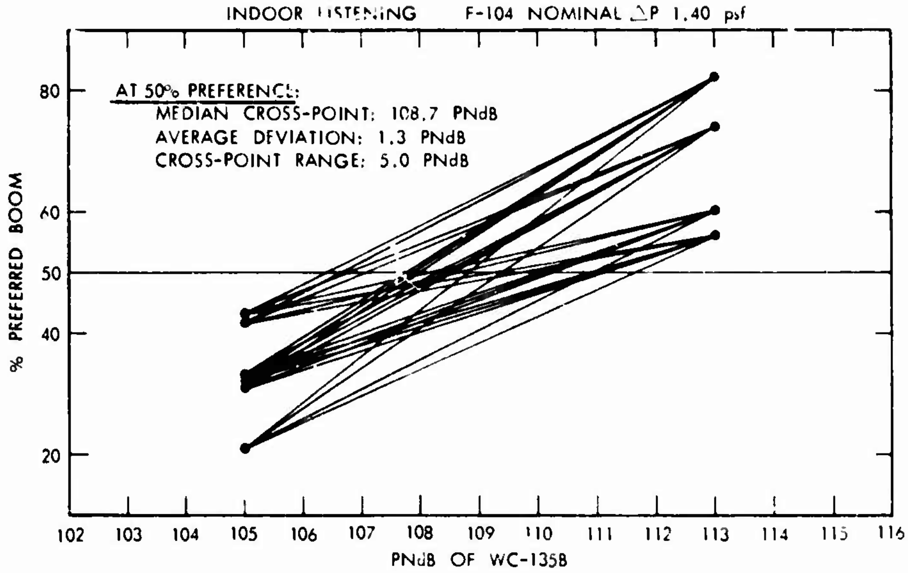
Table D-1 gives the average range of the deviations of all possible cross-points for each of the major experimental conditions tested and shows that, in general, the average of the differences between the median of the crossing points (Figs. 1-5 in the main text and crossing points for any curve drawn between any two data points is about 1 PNdB for any test condition or group of subjects. The total range of the differences among the crossing points for any test condition or group of subjects averages about 4 PNdB.

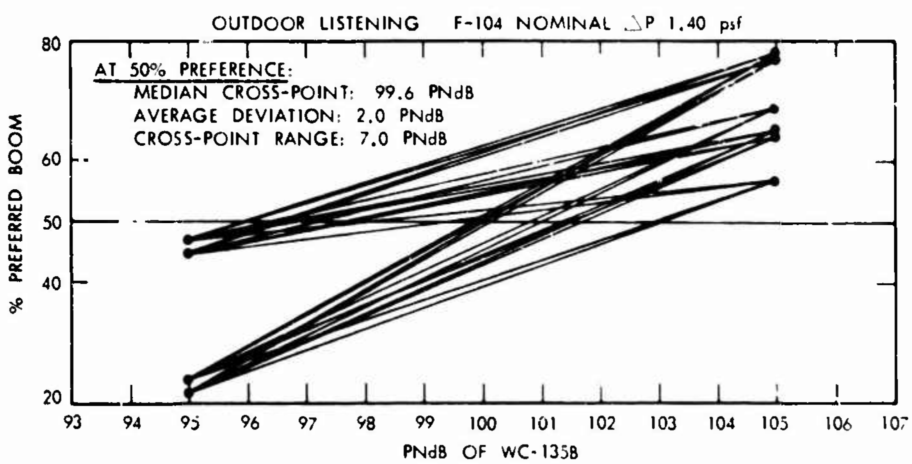
The above results were given in the Interim Report (July 1967). This treatment of the data tends to overstate the variability that was present. Further analysis of the physical data, after the Interim Report was published, indicated that the variation could be reduced. The figures and table are reproduced, as previously reported, to give the larger, conservative estimate.



NOTES: Each data point is the average preference for two missions; one mission being a Boom-Noise mission and the other a Noise-Boom mission. From four missions (Boom-Noise Test, Boom-Noise Retest, Noise-Boom Test and Noise-Boom Retest) four data points can be formed. With one set of four points above the 50% line and another set of four points below the 50% line, sixteen lines will intersect the 50% preference line. The average deviation is $1/N \sum_{i=1}^{N} \left| x_i - \text{median cross-point} \right|$ where N is the number of cross-points and x_i is the value of the i^{th} cross-point.

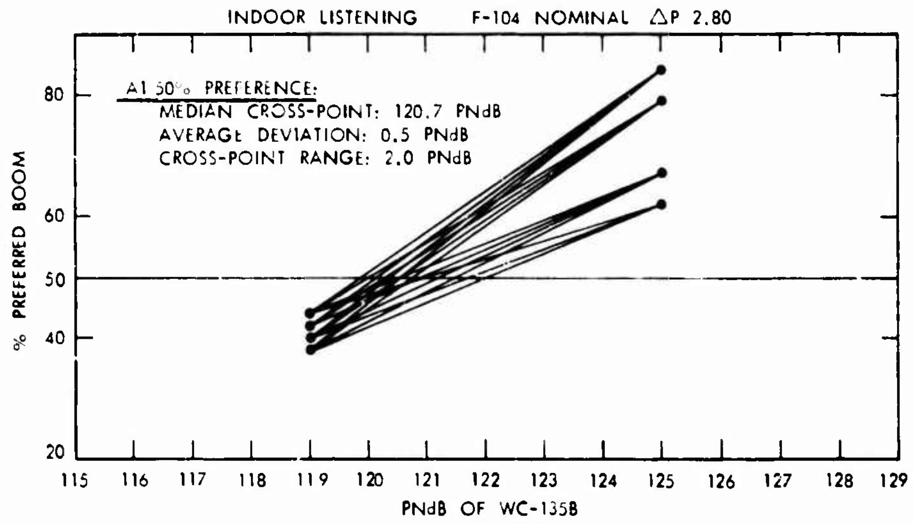
FIG. D-1 VARIATION OF PAIRED-COMPARISON JUDGMENTS (F-104 nominal ΔP 0.75 psf vs. WC-135B). Listeners from Edwards AF Base.

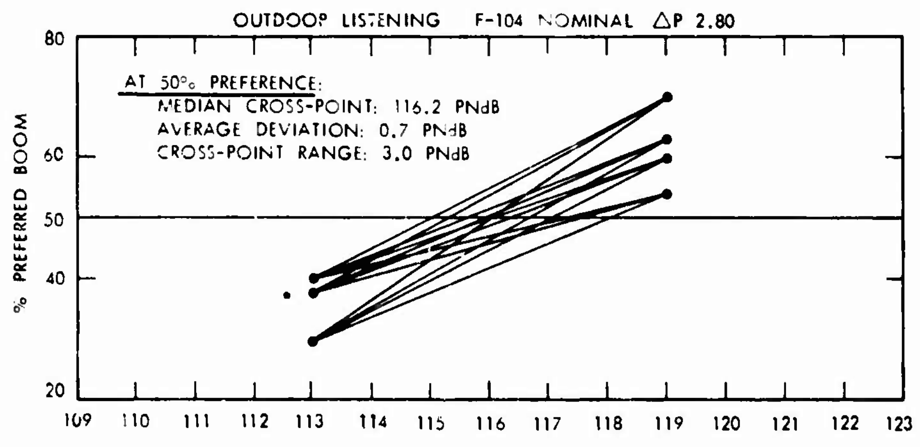




NOTES: See Fig. B-4-1 for general notes.
*Two Boom-Noise missions and three Noise-Boom missions were flown, consequently, six data points can be formed.

FIG. D-2 VARIATION OF PAIRED-COMPARISON JUDGMENTS (F-104 nominal ΔP 1.40 psf vs. WC-135B). Listeners from Edwards AF Base.





NOTES: See Fig. B-4-1 for general notes.
*Three Boom-Noise missions and one Noise Boom mission were flown, consequently, only three data points can be formed.

FIG. D-3 VARIATION OF PAIRED-COMPARISON JUDGMENTS (F-104 nominal ΔP 2.80 psf vs. WC-135B). Listeners from Edwards AF Base.

Table D-1

VARIATION OF PAIRED-COMPARISON JUDGMENTS FOR SONIC BOOM VS SUBSONIC NOISE PAIRS

	Aircraft Identification				Indoor Listening		Outdoor Listening		
Listeners	Sonic Boom A/C	Nominal ΔP (psf)	Subsonic Noise A/C	Power	Average* Deviation (PNdB)	Range* (PndB)	Average* Deviation (PNdB)	Range* (PNdB)	Comment
Edwards AF Base	F-104	0.75	WC-135B	Takeoff	1.3	4.5	2.1	8.0	Fig. D-1
	F-104	1.40	"	Takeoff	1.3	5.0	2.0	7.0	Fig. D-2
	F-104	2.80	"	Takeoff	0.5	2.0	0.7	3.0	Fig. D-3
	B-58	1.69	KC-135	Landing	0.3	1.1	1.0	5.0	Missions where the B-58 exceeded deviation criteria (for altitude, mach or lateral distance) were excluded from the analysis.
	B-58	1.69	"	Takeoff	1.0	2.7	1.6	6.3	
	B-58	2.65	"	Landing	0.5	1.6	0.8	2.7	
	B-58	2.65	"	Takeoff	2.1	4.0	1.0	2.0	
				Av.	1.0	Av. 3.0	Av. 1.3	Av. 4.9	
Fontana	B-58	1.69	WC-135B	Takeoff	1.1	4.2	0.9	3.4	Average deviation value and range value for indoor listening were estimated at the 20% preference line instead of the 50% preference line. (See Fig. 3, in main text)
Redlands	B-58	1.69	WC-135B	Takeoff	1.5	5.8	1.0	3.5	Average deviation value and range value for outdoor listening were estimated at the 70% preference line instead of the 50% preference line. (See Fig. 3, in main text)

* See Figure D-1 for additional notes and illustrations of crosspoints.

The average deviation is $\frac{1}{N} \sum_{i=1}^{N} \left| X_i - \text{median crosspoint} \right|$ where N is the number of crosspoints and X_i is the value of the i^{th} crosspoint.

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13. ABSTRACT

A series of tests were conducted at Edwards Air Force Base in June 1966 and October 1966 to January 1967 in which human subjects (located indoors and outdoors), and special test structures were exposed to booms from F-104, F-106, B-58, SR-71, and XB-70 supersonic aircraft, and the noise from KC-136 and WC-135B subsonic aircraft.

Physical measurements were made of the sonic boom signatures, subsonic aircraft noise, and the response of structures to the booms and noise. Psychological measurements were made of the subjective acceptability to several hundred subjects of the booms and subsonic aircraft noise.

Details of the test plan and procedures, and the results of the data analyzed are presented.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Sonic Booms:						
Physical Measures						
Propagation						
Weather Effects						
Effects on People						
Energy Spectra						
Response of Structures						
Comparison with Noise						

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